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Final Report

THE DEVELOPMENT OF A NONCRYOGENIC NITROGEN/OXYGEN SUPPLY TECHNIQUE

OFFICE OF PRIME RESPONSIBILITY

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by B. M. GREENOUGH

Prepared Under Contract NAS9-10405

BIOTECHNOLOGY

LOCKHEED MISSILES & SPACE COMPANY

Sunnyvale, California

for

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Manned Spacecraft Center

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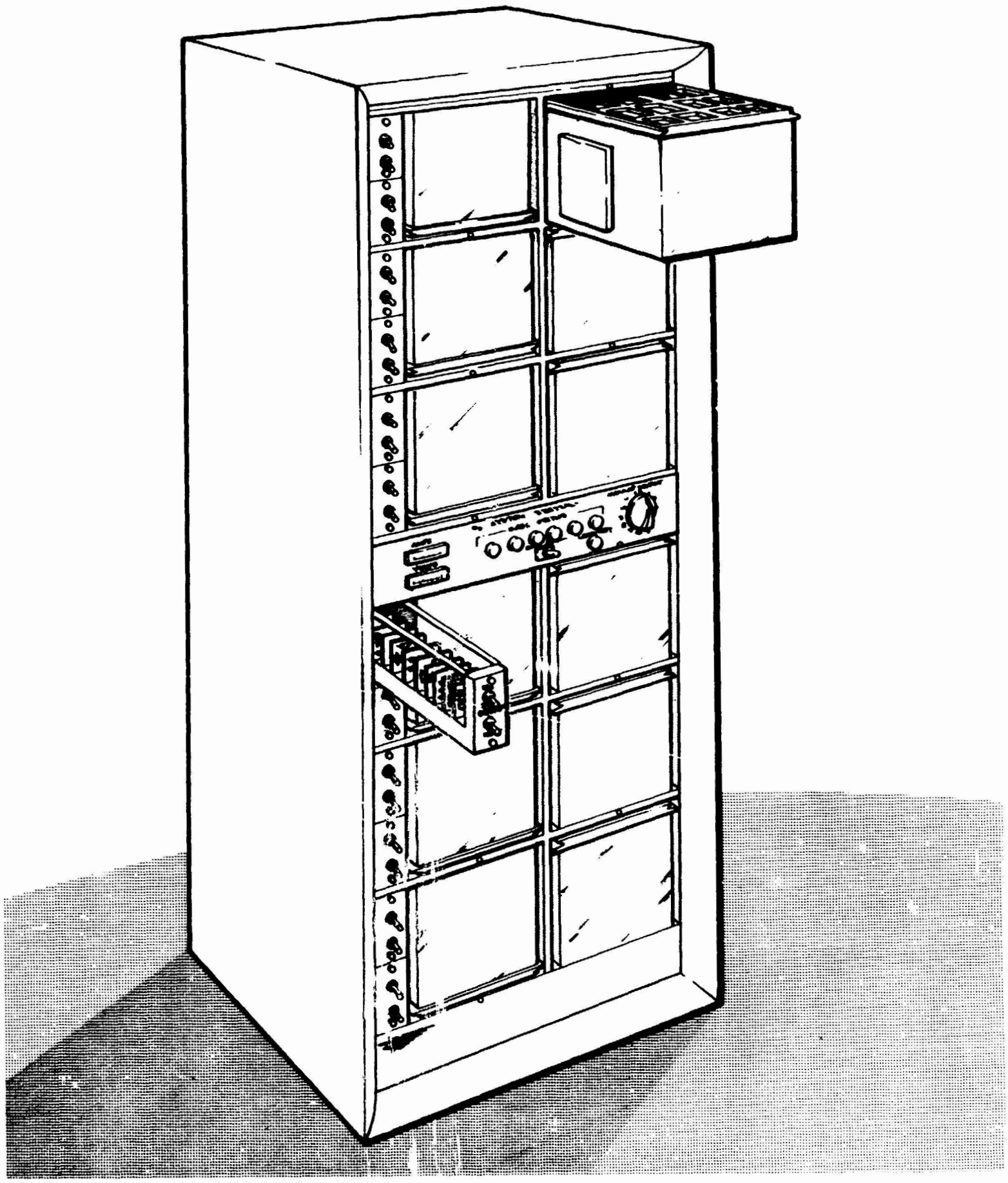

Frontispiece – Space Station O_2/N_2 Generation System

LIST OF CONTRIBUTORS

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ABSTRACT

A development program was conducted in two phases to define the characteristics and requirements of an electrochemical oxygen/nitrogen supply technique for space station application. In Phase I, electrode formulations and structures suitable for use as anodes in an oxygen/nitrogen generator were experimentally investigated. A one-man model oxygen/nitrogen generator integrated with a space cabin atmosphere simulator was fabricated and successfully tested in Phase II. Data from these tests were used to update a computer routine model of the cabin atmosphere control using the oxygen/nitrogen generator technique. A specification and preliminary design for a 12-man oxygen/nitrogen generation system was prepared.

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SUMMARY

A development program was conducted concerned with the use of a hydrazine/water electrolysis technique to provide both the metabolic oxygen for crew needs and the oxygen and nitrogen for cabin leakage makeup. A laboratory breadboard model one-man O_2/N_2 generation system was integrated with a cabin and metabolic/leakage simulator to provide a testbed for determining cabin atmosphere control characteristics and for evaluating components.

Experimental electrodes were developed and were successfully operated in the one-man model system.

A zero-gravity closed reservoir system including a bubble separator was evaluated.

Control of the total pressure and oxygen partial pressure in the cabin simulator was demonstrated in a series of runs of the integrated system.

A computer routine model of the O_2/N_2 system was updated and revised based on the experimental data from the integrated system testing. This updated computer model predicts adequate control of a 12-man space station under orbital conditions.

A preliminary design and specification for a full-scale 12-man O_2/N_2 system suitable for space station use yielded a total system weight of 862 lb, including spares, and power consumption of 7,830 watts with redundancy and sparing to a reliability of 0.9986 for a 180-day mission.

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Section 1
INTRODUCTION

For extended space-base and space-station manned missions, an oxygen/nitrogen cabin atmosphere will be utilized. The inert diluent will reduce the fire hazard of the oxygen and will enhance the physiological habitability of the environment.

Oxygen consumed metabolically by the crew is recovered from metabolic wastes in a water/waste management and regenerative life support system and is recycled to the cabin. Water electrolysis is a process considered for use in this cycle to recover oxygen from water and provide hydrogen for carbon dioxide reduction.

Losses in cabin atmosphere due to cabin leakage necessitate storage of oxygen and nitrogen for leakage makeup on long-duration missions. For a mission of less than 30 days, it may be practical to carry nitrogen and oxygen onboard the spacecraft using either cryogenic or high-pressure gaseous storage. For an extended mission, however, the weight penalty associated with cryogenic or high-pressure gaseous tankage is excessive.

The development program described herein is concerned with the use of a hydrazine/water electrolysis technique to provide both the metabolic oxygen for crew needs and the oxygen and nitrogen for cabin leakage makeup. With this system, oxygen and nitrogen are stored chemically as water and hydrazine in low-pressure (and therefore low-weight) tankage. This system also has the feature of providing automatic control of the space cabin total pressure and oxygen partial pressure.

The primary objectives of the program were to acquire test data on a laboratory model of the oxygen/nitrogen system and to provide a preliminary design for a 12-man prototype system. The program involved two major areas of effort consisting of (1) electrode and cell development and (2) the assembly and test of a one-man model system to

provide data for the preliminary design. A computer routine model of the oxygen/nitrogen system control of a space cabin atmosphere, developed previously under Contract NAS1-7706, was updated on the basis of the model system test data.

The specific tasks that were completed in meeting the program objectives were as follows:

- Electrode active material development
- Electrode structure and fabrication techniques
- Component selection
- Computer analyses
- Breadboard system assembly
- Breadboard system test
- Preliminary design of prototype system

These tasks were accomplished by analytical and experimental investigations in the following areas:

- Experimental electrodes were fabricated using various formulations, structures, and processing techniques. Performance was evaluated using a potentiostatic apparatus and an electrolysis cell test facility.
- Performance of system components was evaluated experimentally in a one-man model system. Performance characteristics were established for an oxygen partial pressure and total pressure control system, a cabin and metabolic/leak simulator, a zero-gravity water feed system, a zero-gravity bubble separator, and a hydrazine flow control system.
- Automatic control of a cabin simulator total pressure and oxygen partial pressure was demonstrated with the model oxygen/nitrogen generation system in a series of tests.
- Computer analyses were made in conjunction with the system testing to update the computer routine model. Test results were used to verify the updated computer routine.

- A preliminary system design effort culminated in the design of a 12-man oxygen/nitrogen generation system capable of providing a nominal supply of 26.1 lb/day of oxygen and 8 lb/day of nitrogen. The design includes a maximum load capability of 33.2 lb/day of oxygen and 22.6 lb/day of nitrogen.

The sections that follow in this report are concerned primarily with the areas of electrode development, system testing, and computer analyses. The computer routine and the preliminary system design have been documented separately with a computer utilization manual (Ref. 1) and preliminary design and specification report (Ref. 2).

Section 2
RESULTS AND TECHNICAL DISCUSSION

2.1 ELECTRODE DEVELOPMENT

2.1.1 Electrode Design Requirements

The electrode, an integral part of the electrolysis unit, must meet rigid electrical and physical requirements. (Refs. 3 and 4.)

The basic components of the electrode assembly in the LMSC electrolysis unit are: (a) rim, (b) catalytic surface, and (c) catalyst. Functions of these components are:

- The rim besides serving as a rigid support, provides a path for current and voltage.
- The catalytic surface is the center of the electrolysis process.
- The catalyst's primary function is to reduce the chemical activation overpotential.

The design of the rim and the use of platinum black in a Teflon catalytic surface were established at the beginning of the program. Accordingly, all developmental effort was centered on the fabrication and application of a Teflon/platinum (Pt) surface on a nickel screen.

Theoretically, a catalytic surface can be divided into two main parts, one to provide physical strength and "flow through" properties for reaction gases and reactants, and a second part to provide maximum reactive area for the electrolysis process.

In actual operation, the matrix must provide a wettable or hydrophilic surface for the electrolyte to function and a pore structure with enough hydrophobicity to transfer the

reaction gases and repel the electrolyte. The pore structure must not be too dense so as to block the gas flow.

Another property that is important is electrical conductivity. Resistance must be low. Thus, the ideal electrode might be one with a maximum hydrophilic conductive reaction area as well as a porous hydrophobic structure for efficient gas passage.

Attainment of the above with Teflon and platinum is primarily a fabrication problem. In order to improve application of experimental mixes and conductivity of the final matrix, acetylinic carbon was added. The carbon also helped reduce the hydrophobic properties of the Teflon.

2.1.2 Test Facilities

The following two test facilities were available:

- Immersed Electrode Polarization Apparatus
- Laboratory Model Electrolysis Cell Apparatus

Immersed Electrode Polarization Apparatus. In order to study initial performance characteristics of the experimental electrodes, the Immersed Electrode Polarization Apparatus was designed and built. (See Fig. 2-1.) This apparatus is essentially two H cells – electrolysis and reference units, respectively – connected by an electrolyte bridge. The reference unit is equipped with three standard platinum electrodes, two for hydrogen and oxygen production and the third for a point of reference. The counter and working (experimental) electrodes are located in the electrolysis unit. The complete cell holds 300 cc of 30-percent potassium hydroxide solution.

A WENKING potentiostat is used to control and measure variations in voltage and current between the reference and working electrodes. Both units are vented to the hood.

This apparatus provides a quick and accurate evaluation of the effective surface area or reaction zone of candidate electrodes prior to final testing in the laboratory model electrolysis cell.

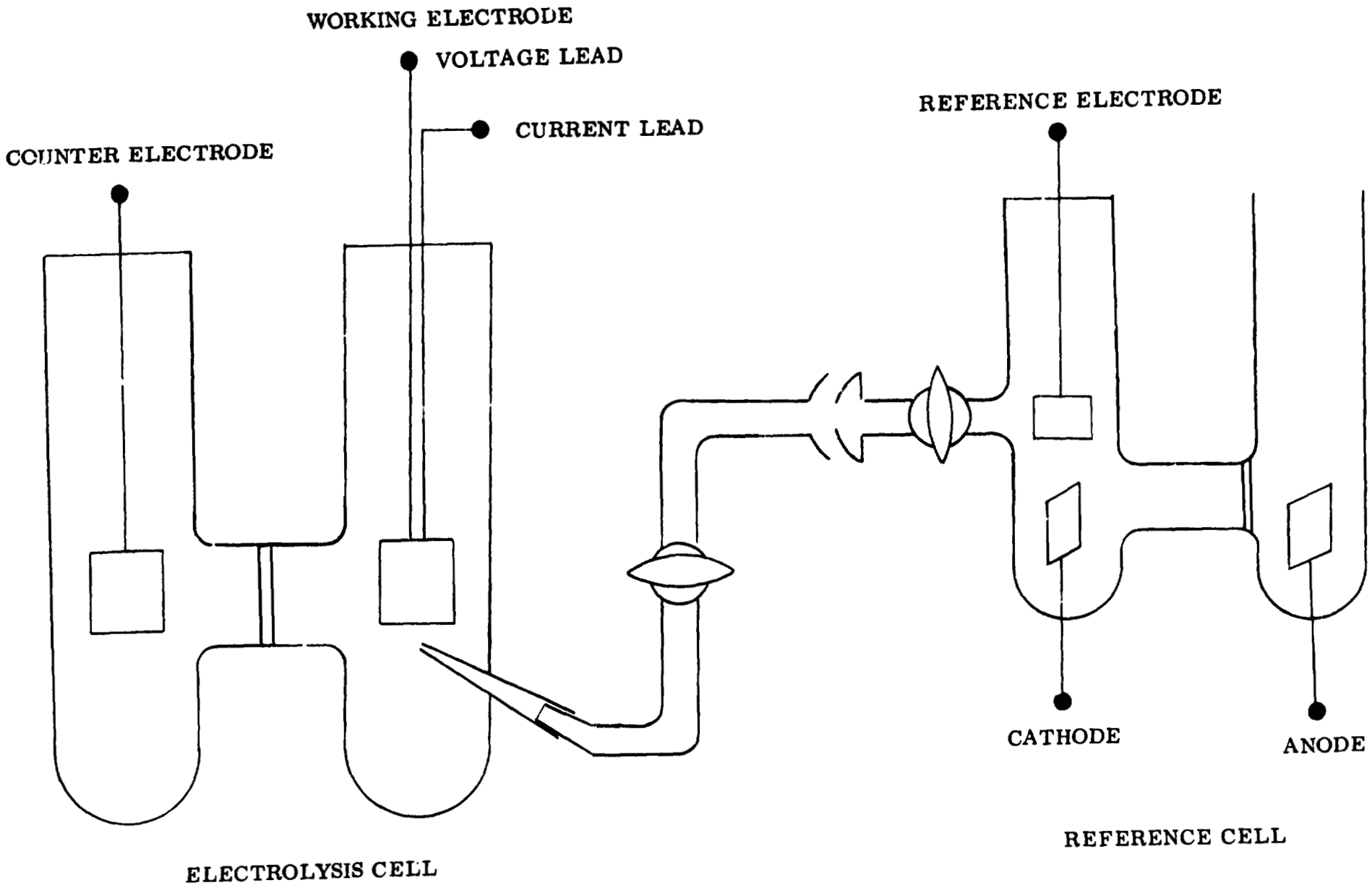


Fig. 2-1 Immersed Electrode Polarization Apparatus

Electrode samples were cut to a 1 × 2 cm size and spotwelded on a nickel lead. Data points were obtained from the electrode samples by measuring the reference voltage vs. the working voltage for different current densities.

Laboratory Model Electrolysis Cell Apparatus. The Laboratory Model Electrolysis Cell Test Facility designed and built by LMSC (Contract NAS1-7706) is routinely used for the purpose of obtaining long-term electrolysis cell data and for general cell development. In contrast to the Immersed Electrode Polarization Apparatus, this test facility simulates actual operational conditions. Four test stations are available. Each station is provided with the necessary inputs of current-controlled electrolysis power, an auxiliary ac power source, coolant, feed water, and inert gas purge. Ammeters are used for current readout, and both digital and strip chart readouts are used for voltage. A complete description follows.

Two test stations are shown in Fig. 2-2. The electrolyte circulation loop components can be seen in this figure. Electrolyte leaving the electrolysis cell is discharged into a reservoir. A magnetically-driven, plastic centrifugal pump is used to circulate the electrolyte. From the pump, the electrolyte is passed through an all-plastic shell and tube heat exchanger in which cold ethylene glycol flows through the shell side. A plastic valve is used to adjust the electrolyte flow as indicated by a flowmeter. After passing through the flowmeter, the electrolyte is returned to the cell. (See Section 2.2.1 for a complete description of the cell configuration.)

After startup, the operation of a cell is completely automatic. The main control functions are cell temperature and water feed. Cell temperature control is maintained with a miniature thermoswitch located at the electrolyte discharge from the cell. This switch provides a signal to a solenoid valve to provide coolant on demand. A heating circuit also is provided to permit testing at temperatures above ambient. Water feed control is achieved with a level control switch that provides a signal for liquid water feed to the reservoir on demand. Because the test stations were designed for automatic operation and unattended operation on a 24-hr a day basis, a number of safety

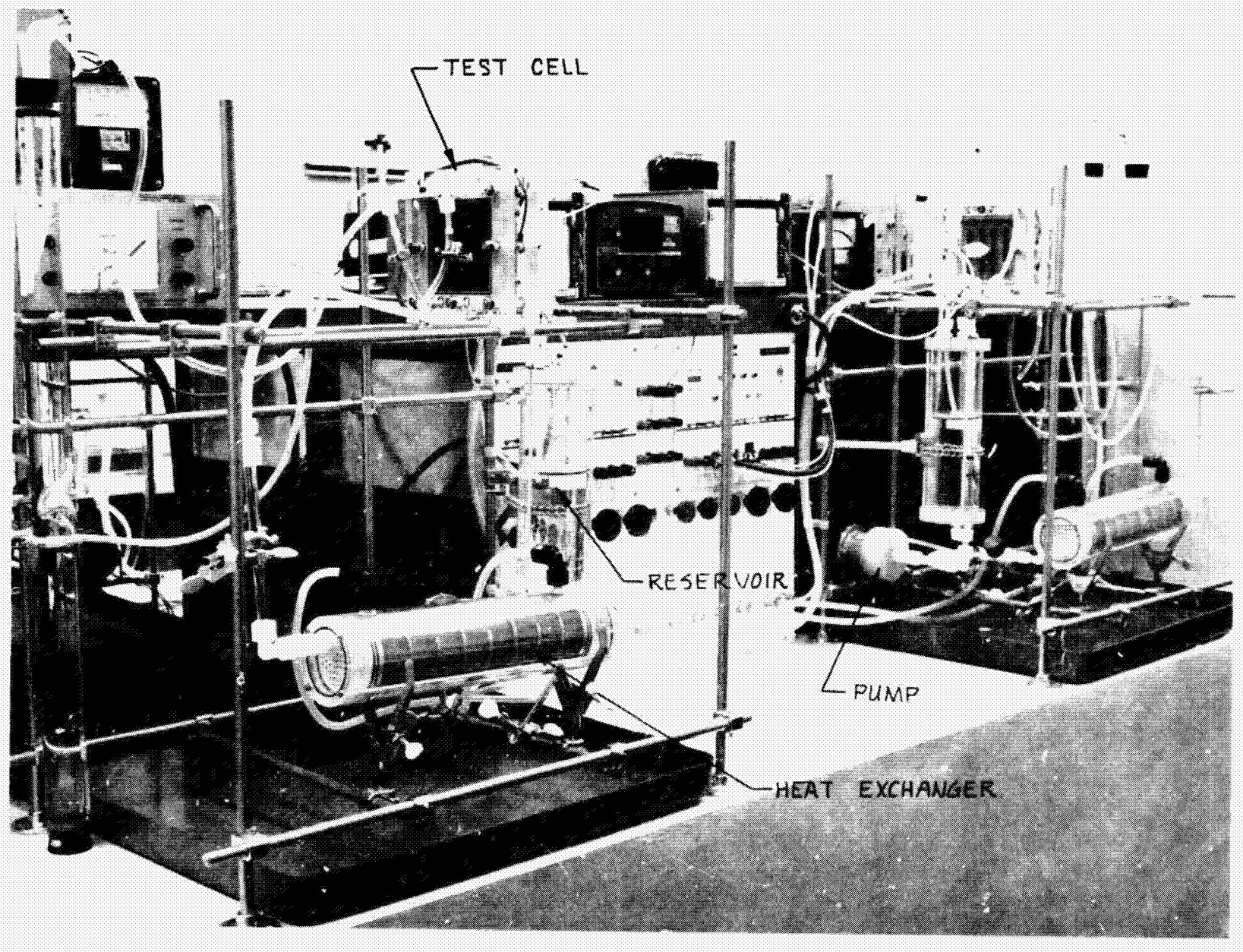


Fig. 2-2 Electrolysis Cell Test Stations

functions were built into the control panels shown in Fig. 2-3. During normal operation, panel lights indicate the electrolyte cooling and heating cycles, that the pump is operating, and that the purge-gas (N_2) solenoids are closed. Unsafe operating conditions, if they occur, are indicated in the upper row of panel lights. Unsafe conditions would exist if there were no electrolyte flow; the electrolyte level in the reservoir were too high or too low; or the cell temperature were too high.

In the event of an unsafe condition, the safety circuit is activated to automatically shut down the test station. Electrolysis cell power is turned off; the pump, coolant, and water feed go off; and nitrogen purge to both sides of the cell is turned on. The panel light for whichever safety function shuts down the station remains on, indicating the cause of shutdown, until it is reset. All of the safety circuits contain latching relays to prevent the station from being reactivated automatically before the cause of the unsafe condition can be rectified.

Differential pressure control between the gas and electrolyte phases is accomplished by discharging electrolyte from the cell below the level of the inet. This provides a suction pressure in the electrolyte so that the generated gases can be discharged at ambient pressure and still maintain a positive gas-over-liquid pressure. Although it is not necessary for maintaining sufficient gas-back pressure, the generated gases are generally discharged into bubblers with a few inches of water back-pressure to give a visual indication of gas generation.

Cell performance data are automatically recorded on a continuous basis with an automatic data logging system utilizing a high-speed typewriter, digital clock, digital voltmeter, and multichannel scanner.

2.1.3 Cell Tests – Operating Parameters

Voltage vs. Current Density. The voltage-current density relationship (polarization curve) for an electrolysis cell is the primary descriptor of its performance. Because the gas generation rate is Faradaic, the power required to produce a given amount of

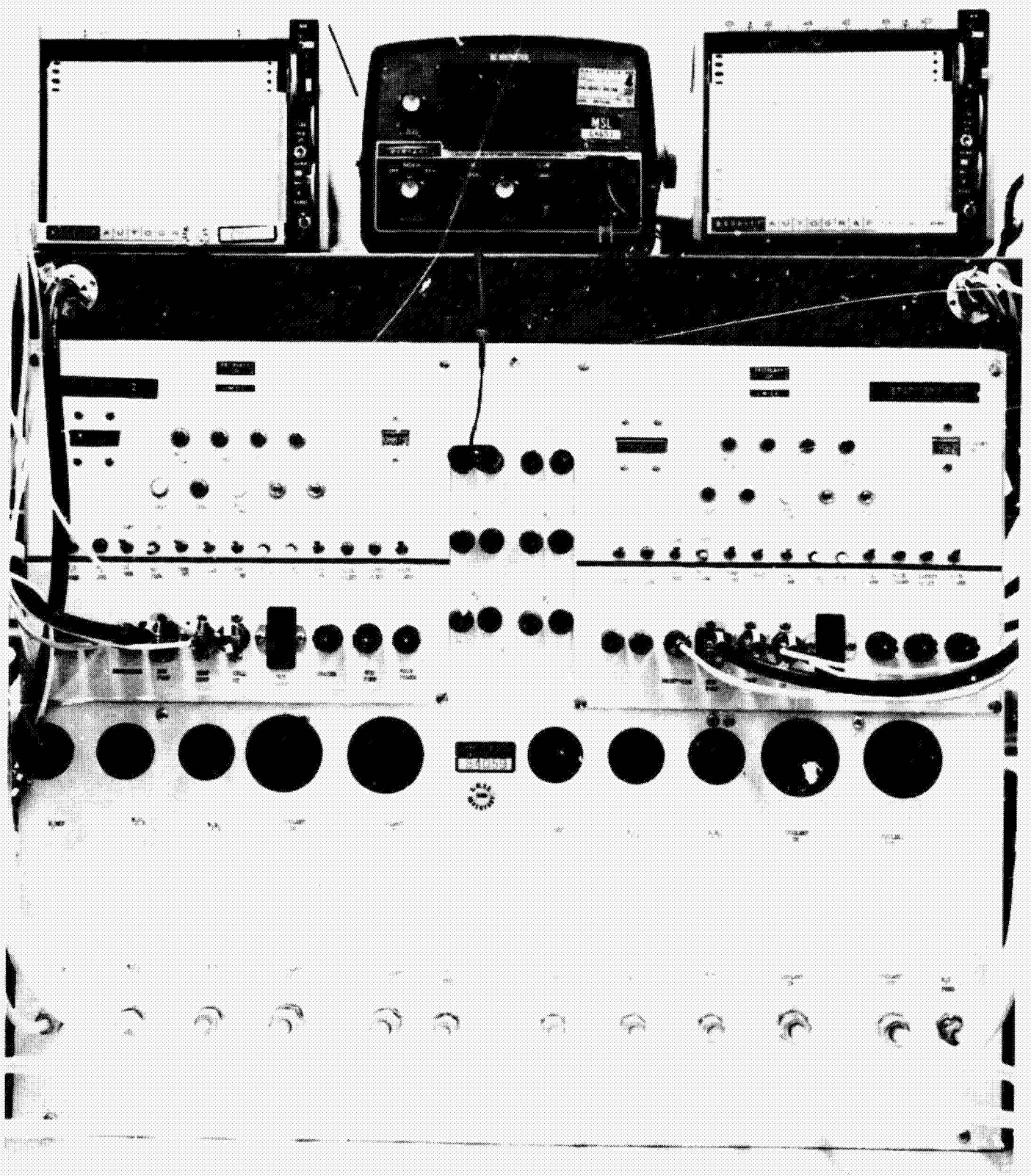


Fig. 2-3 Electrolysis Test Station Control Panels

gas is directly proportional to the cell voltage. It is, therefore, desirable to have a cell with a "flat" polarization curve, i.e., minimum voltage change with increasing current. This also applies to the small polarization apparatus measurements.

The cell voltage is the sum of four components:

$$V_{cell} = V_{oc} + V_{ir} + \eta O_2 + \eta H_2 \qquad (2.1)$$

where

V_{oc} = theoretical open-circuit cell potential

V_{ir} = IR loss

ηO_2 = oxygen overvoltage

ηH_2 = hydrogen overvoltage

The theoretical open-circuit cell potential for hydrogen and oxygen is 1.23 V. However, in an actual device, the open-circuit potential is closer to 1.0 V due to a mixed potential at the oxygen electrode. When current is passed between the electrodes, a voltage drop (or IR loss) is produced because of the cell resistance. For a given cell configuration, the resistance is fixed and the IR loss is proportional to the applied current.

The overvoltage contributions to the cell voltage are a complex function of catalytic activity of the active electrode material and the mechanism of the reaction at each electrode. A number of contributions to the literature have advanced theories to explain the existence of overvoltages and mechanisms of the reactions. These theories have been conflicting in most cases and no one explanation has gained universal acceptance.

While it is possible to determine electrode overvoltages by physical measurement in bulk electrolyte (Ref. 5), the use of these data to predict electrode performance in a practical cell is complicated by the presence of the matrices. A more practical

approach that was taken in this program was to insert a standard hydrogen reference electrode in the external electrolyte circulation loop. The voltages that were then monitored were related by:

$$V_{cell} = V_{O_2} + V_{H_2} \tag{2.2}$$

where

V_{O_2} = oxygen electrode potential vs. standard hydrogen

V_{H_2} = hydrogen electrode potential vs. standard hydrogen

Comparing Eq. (2.2) with Eq. (2.1) it is seen that V_{O_2} and V_{H_2} each include a part of the open-circuit potential, V_{OC}, and the IR loss, V_{IR}, in addition to the overvoltage. At open circuit, V_{H_2} is zero and V_{OC} is equal to V_{O_2}. Since only the total cell resistance and not the resistance distribution across the cell was measured, the IR loss contribution to each electrode and absolute values of overvoltage could not be determined from the measurements of V_{O_2} and V_{H_2}.

These potentials, which will be referred to in subsequent sections as "electrode polarization," are useful parameters for evaluating electrolysis cell performance and give additional insight into the operating characteristics of different electrode and matrix materials and the effect of other operating parameters.

A typical electrolysis cell polarization diagram is shown in Fig. 2-4. The voltages shown are initial values and do not reflect long-term performance changes. The polarization of the oxygen electrode is more than three times as severe as that of the hydrogen electrode, and it is evident that cell performance improvement is more likely to be achieved by reducing the oxygen electrode polarization.

Temperature and Electrolyte Concentration. The cell temperature and KOH electrolyte concentration are operating parameters that are independent of each other in that each

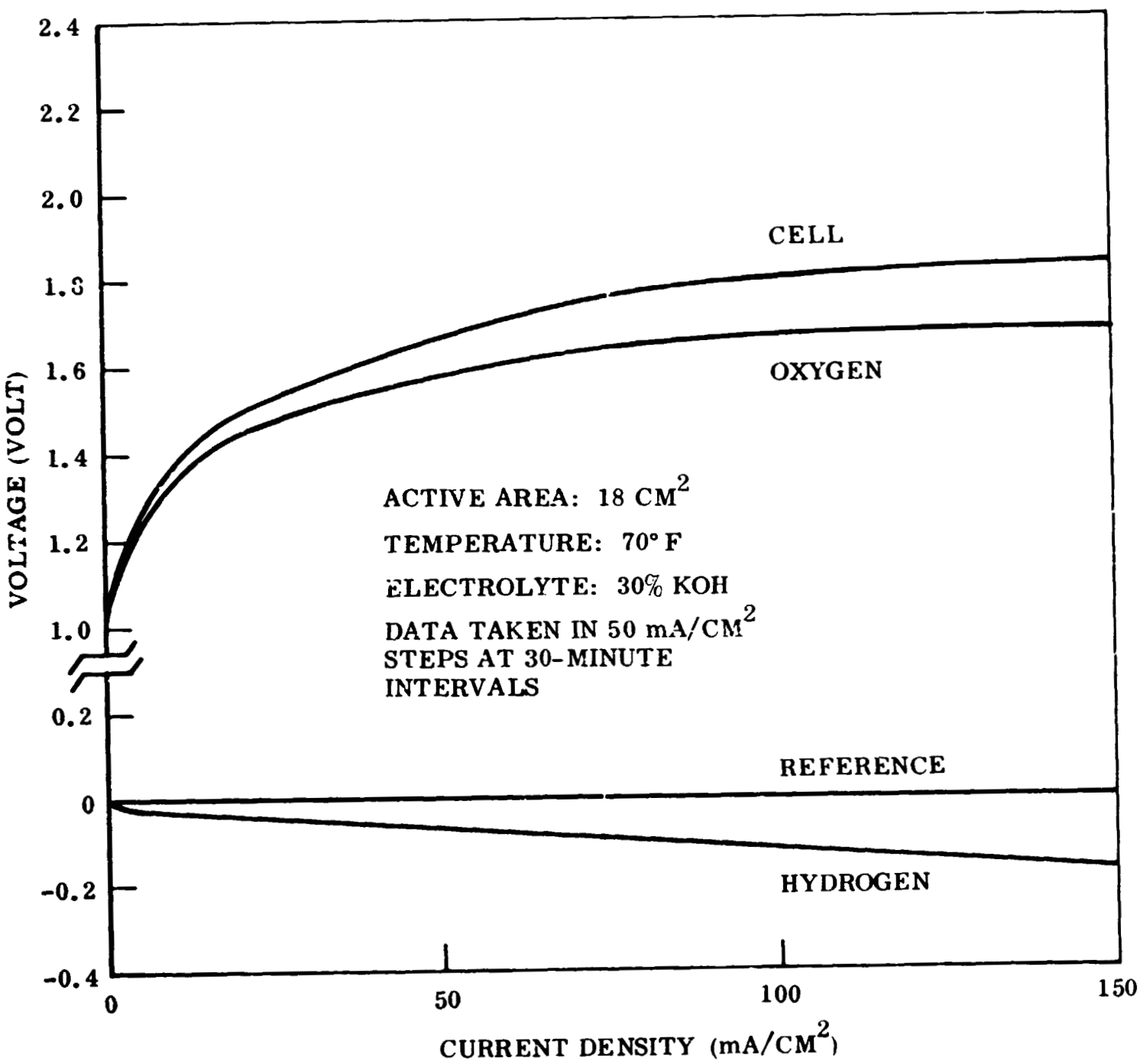


Fig. 2-4 Electrolysis Cell Polarization

can be set arbitrarily and controlled without regard to the other. Their effects on the operating characteristics of the cell, however, are interrelated. The first criterion for choosing the optimum electrolyte concentration is to minimize the internal cell IR loss. As can be seen in Fig. 2-5, the minimum electrolyte resistance occurs between 25 and 30 weight percent.

The effects of temperature are two-fold: first, the temperature affects the operating cell voltage; and second, it affects the absolute humidity of the generated gases.

2.1.4 Experimental Results and Discussion

A summary of the experimental electrode testing that was conducted is presented in Table 2-1.

The following materials were used in the experimental work:

Material	Source
Teflon (TFE) Powder TL 126	Liquid Nitrogen Processing Corp.
Teflon Industrial Finish 50% TFE Teflon Suspension	E. I. Dupont DeNemours & Co.
Black Platinum	Englehard Co.
Nickel Powder	LMSC
Graphite	–
Expanded Nickel Screen	Exmet Diemesh Corp.

2.1.4.1 Preliminary Formulations

Initial work was confined to a Teflon/catalyst mix with the following desired properties:

- It must be easily applied to a nickel screen.
- The final catalytic surface must be hydrophilic, conductive, and porous.
- It must adhere to the screen.

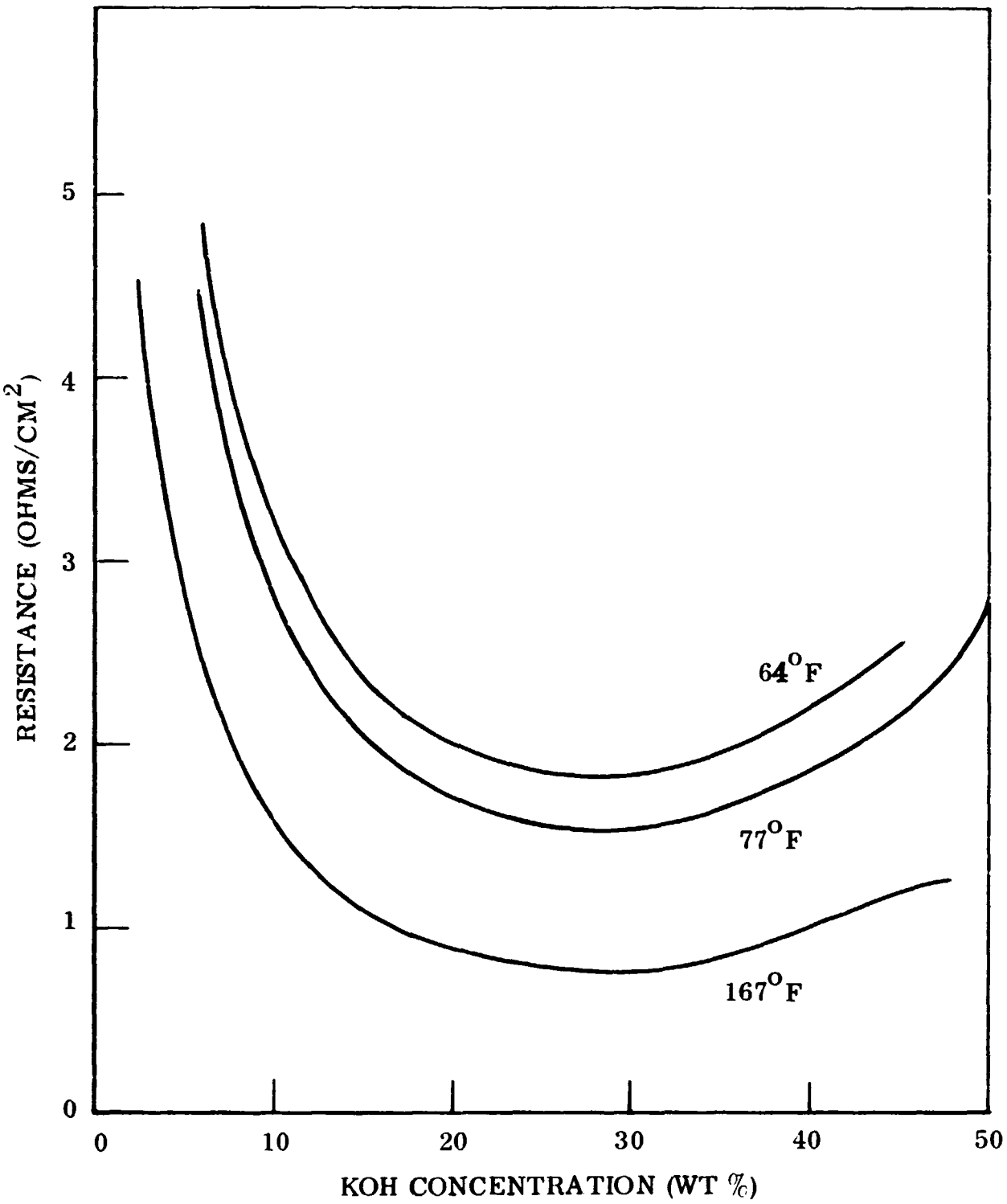


Fig. 2-5 Electrolyte Resistance vs. Concentration

Table 2-1

EXPERIMENTAL ELECTRODE TEST SUMMARY

Electrode Number	Catalyst Load (mg/cm^2)	Type of Test	Anode Voltage (V)	Current Density (mA/cm^2)	Test Time (hr)	Comments
T-1	Ni 87	Conductivity				Electrode surface nonconductive
T-2	Ni 50	Conductivity				Electrode surface nonconductive
T-3	Ni	Processing				Mixture would not adhere to substrate
T-4	Pt 13	Processing				Formed nonconductive film
T-5	Pt 12	Processing				Formed nonconductive film
T-6	Pt 9	Processing				Formed nonconductive film
T-7 through T-18	Pt	Processing				No measurements made
T-19	Pt 20	Polarization	1.85	75	2	Disintegrated
T-20	Ni 20	Polarization				Immersed test – see Fig. 2-6
T-21	Ni 20	Polarization	2.00	50	2	Immersed electrode polarization test
T-22	Ni 30	Polarization	2.00	125	2	Immersed electrode polarization test
T-23	Ni 30	Polarization	2.00	150	2	Immersed electrode polarization test
T-24	Ni 45	Polarization	2.00	150	2	Immersed electrode polarization test
T-25	Pt	Processing				Mixture did not adhere to substrate
T-26 through T-28	Pt	Processing				
T-29	Pt 16	Polarization	2.00	50	2	Immersed electrode polarization test
T-30	Pt 20	Polarization	2.00	38	2	Immersed electrode polarization test
T-31	Pt 20	Polarization	2.00	80	2	Immersed electrode polarization test
T-32	Pt 40	Polarization	2.00	35	2	Immersed electrode polarization test
T-33	Pt 80	Polarization	2.00	115	2	Immersed electrode polarization test
T-34	Pt 25	Processing				No measurements made
T-35	Pt 26	Processing				No measurements made
T-36	Pt 25	Processing				No measurements made
T-37	Pt 26	Processing				No measurements made
T-38	Pt 20	Processing				No measurements made
T-39	Pt 21	Processing				No measurements made
T-40	Pt 25	Polarization	1.98	150	2	Immersed electrode polarization test
T-41	Pt 25	Polarization	2.00	150	2	Immersed electrode polarization test
T-42	Pt 33	Polarization	2.00	150	2	Immersed electrode polarization test
T-43	Pt 22	Processing				No measurements made
T-44	Pt 16	Polarization	1.82	150	2	Immersed electrode polarization test
T-45 through T-52	Pt	Processing				No measurements made
T-53	Pt 30	Polarization	1.82	150	1	Immersed test – see Fig. 2-7
T-54	Pt 30	Polarization	1.80	150	1	Immersed test – see Fig. 2-7
T-55 through T-62	Pt	Processing				No measurements made
T-63	Pt 35	Polarization	2.2	150	7	Immersed electrode polarization test
T-64	Pt 35	Polarization	1.8	120	1	Immersed test; cellulose acetate binder
T-65 through T-70	Pt	Processing				Scale-up to 18 cm^2 size
T-71	Pt 22	Electrolysis	2.18	150	294	See Fig. 2-10. 18 cm^2
T-72	Pt 22	Electrolysis	2.10	150	200	See Fig. 2-10. 18 cm^2
T-73 through T-86	Pt	Processing				Scale-up to 90 cm^2 size
T 87	Pt 20	Electrolysis	2.3	150	<1	
T-88	Pt 6	Electrolysis	2.4	150	1	
T-89	Pt 11	Electrolysis	2.3	150	2	
T-90 and T-91	Pt 12	Processing				No measurements made
T-92	Pt 20	Electrolysis	2.5	150	7	
T-93 through T-114	Pt	Processing				No measurements made
T-115	Pt 20	Electrolysis	2.3	150	7	
T-116	Pt 20	Electrolysis	2.3	150	3	
T-117 and T-118	Pt	Processing				No measurements made
T-119	Pt 20	Electrolysis				See Fig. 2-10
T-120	Pt 22	Electrolysis	2.3	150	6	
T-121	Pt	Processing				No measurements made
T-122	Pt 22	Electrolysis	2.10	150	136	See Fig. 2-11
T-123	Pt 22	Electrolysis	2.16	150	142	See Fig. 2-11
T-124	Pt 22	Electrolysis	1.88	150	135	See Figs. 2-11 and 2-12
T-125	Pt 22	Electrolysis	1.80	150	35	See Figs. 2-11 and 2-13
T-126	Pt 22	Electrolysis	2.10	150	70	See Figs. 2-11 and 2-14
T-127	Pt 22	Structure				See Fig. 2-8

Accordingly, many experimental formulations were prepared using various forms of Teflon and varying amounts of catalyst. Nickel powder and platinum black were used. The general process was to weigh the ingredients and to mix them with an easily removable solvent such as toluene. The resulting paste was spread on the expanded nickel screen, dried at room temperature, and pressed, either by rolling or pressing at a relatively high pressure. In some cases, the electrode was heat treated.

The initial electrodes did not meet all of the desired properties. Excessive pressures rendered the Teflon a completely hydrophobic film, and excess Teflon had the same effect. Insufficient Teflon did not give the required structural strength to the electrode, and the catalytic surface disintegrated in the electrolyte. Excessive amounts of carbon tended to decrease the structural strength.

There were difficulties encountered in the initial application of the paste on the screen. The fluid paste tended to go through the screen. This problem was solved by backing the screen with a porous Teflon sheet prior to application of the paste. The sheet was then stripped off the completed electrode.

Later on, the nickel screen was coated with a microfilm of Teflon prior to application of the matrix.

The first series of electrodes was prepared using nickel as a catalyst rather than platinum in an effort to reduce experimental costs. These electrodes were relatively simple – merely a mix of Teflon, catalyst, and lubricant applied to a nickel screen. Electrode number T-20 is an example. Its formulation is as follows:

Teflon Powder (TL-126)	21.7 Percent
Nickel Powder	72.0 Percent
Graphite	6.3 Percent

The three ingredients were blended and approximately 0.1 gm of mineral oil was added. The resulting paste was rolled on a screen until a smooth catalytic surface

was formed. After heat treatment at 300°F for 20 minutes, the electrode was washed with toluene to remove the mineral oil, then dried at 100°C.

Conductivity and wettability of the electrode were satisfactory. However, it was not structurally strong. After several test cycles in the immersion polarization apparatus, the catalytic surface disintegrated when subjected to electrolytic action. (See Fig. 2-6.)

In order to improve the structural strength of the matrix, a commercially prepared Teflon suspension was used with the TL-126. Electrode number T-20A is an example.

Teflon Powder	24 Percent
Teflon Suspension	10 Percent
Nickel	48 Percent
Graphite	18 Percent

This electrode also disintegrated.

While certain techniques involved in the handling of Teflon mixes were developed in the work with nickel powder, it was found that substitution of platinum for nickel called for modification of procedures. Also, a decision was made to concentrate on using the Teflon suspension rather than the dry Teflon powder.

Formulations T-53 and T-54 were the first experimental platinum electrodes with electrical and physical characteristics approaching those of the acceptable commercial electrode. The formulation is as follows:

Teflon Suspension	40 Percent
Black Platinum	50 Percent
Graphite	10 Percent

The platinum and graphite were thoroughly blended in 3 to 5 cc of toluene. Then, the Teflon suspension was weighed into the mix and the formulation was worked with a spatula into a homogeneous paste. The paste was spread on a Teflon-backed screen

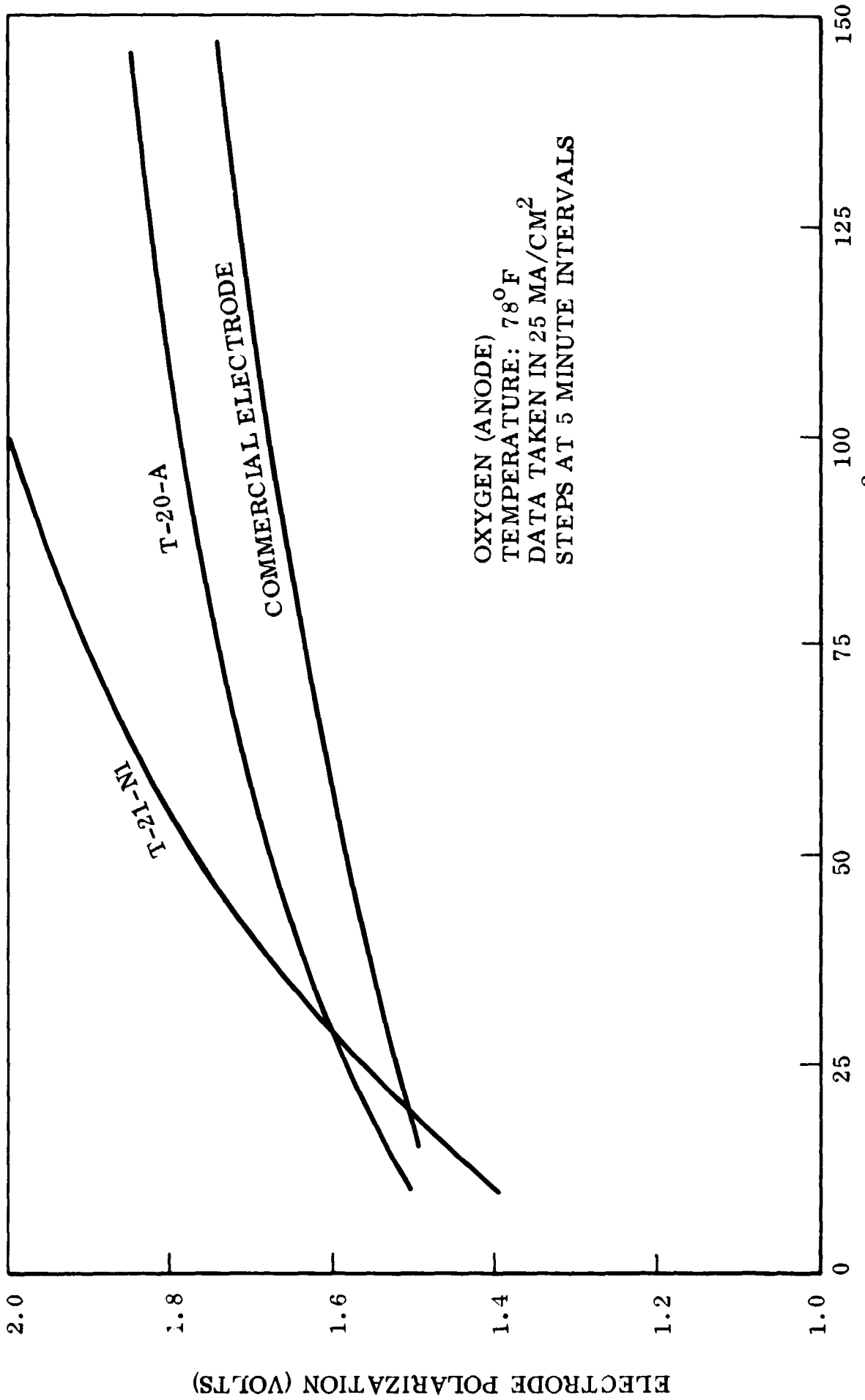


Fig. 2-6 Polarization of Experimental Nickel Electrodes

and rolled gently until it adhered to the screen. The electrode was dried (toluene removed) at room temperature for 2 hr, washed with distilled water, and finally dried in a 100°C oven.

Both T-53 and T-54 were porous, hydrophilic, conductive, and had sufficient structural strength to withstand the action of the 30-percent KOH solution. (See Fig. 2-7.)

During this phase of the work some effort was made to improve the porosity by incorporating a soluble material into the mix and, as a final step, washing the material out, leaving a porous matrix. This method was found to be generally unsatisfactory in that complete removal of the additive was difficult; hence, an impurity in the matrix.

Subsequent mixes using this basic formulation and varying the percentage of platinum from 40 to 60 percent showed that a satisfactory electrode could be prepared. It also was quite evident that the amount of pressing and rolling of the final catalytic surface had a marked effect upon the electrical uniformity of the final electrode. Excessive rolling tended to form a nonporous, nonconductive film. In general, the small electrodes were subjected to four passes through a small hand calendering device.

This phase of the work yielded an electrode that was conductive, hydrophobic, and offered enough catalytic area for efficient oxygen production in an immersed electrode apparatus.

Figures 2-8 and 2-9 are microphotographs of typical catalytic surfaces of an experimental electrode and a commercial electrode. Note the porosity.

2.1.4.2 Electrodes for the Electrolysis Test Setup

Electrodes for this application were scaled up to 18 cm^2 and were circular. Different requirements presented new problems.

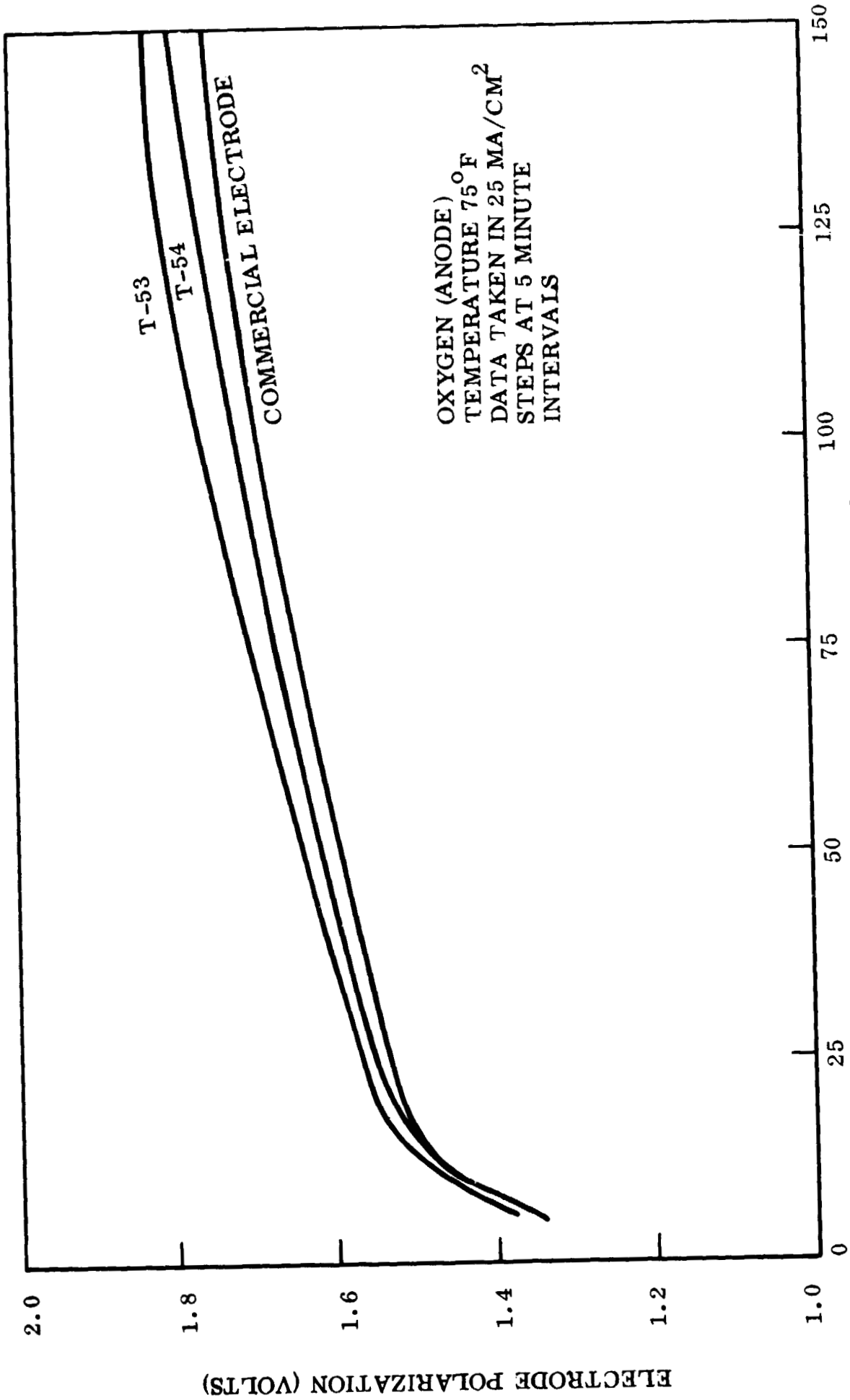


Fig. 2-7 Polarization of T-53 and T-54 Electrodes

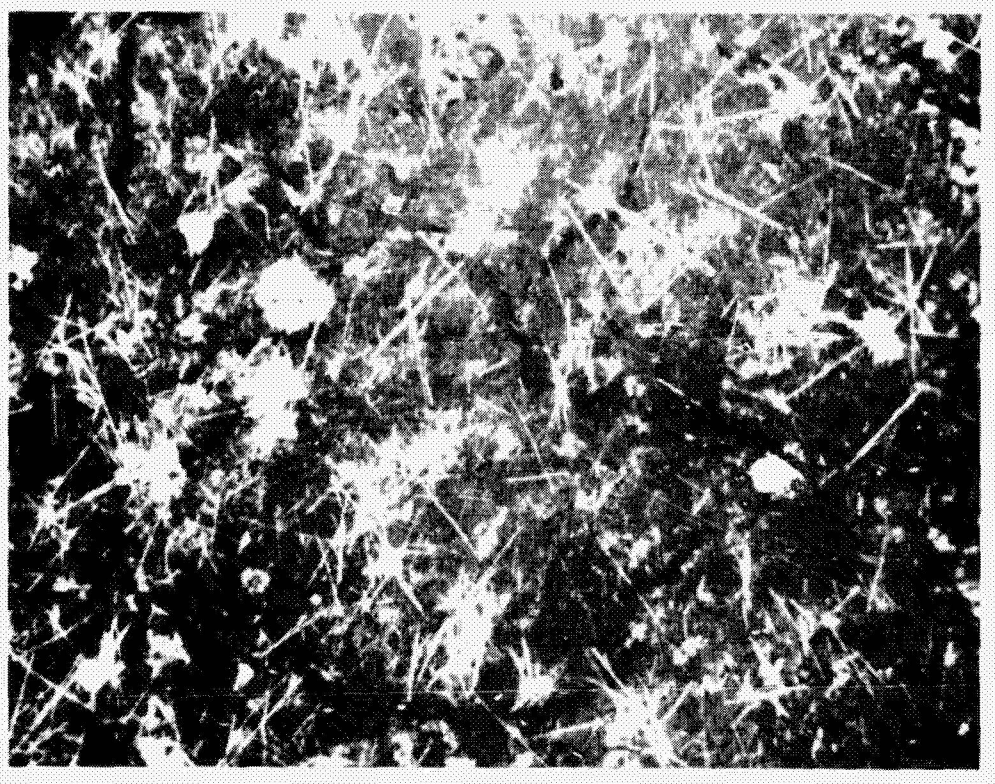


Fig. 2-8 Micrograph of T-127 (80×)

Fig. 2-9 Micrograph of Commercial Electrode (80×)

The two primary electrode requirements for efficient cell operation are as follows:

- The electrode must offer a maximum hydrophilic catalytic surface to the electrolyte.
- The porous inner electrode must be hydrophobic, so that the reaction gases will be transferred.

A totally wet electrode tends to offer a barrier to the gaseous reaction products, and the bubbles of gas, so blocked, will reduce the available catalytic surface of the electrode. A rapid rise in voltage is an indication of this condition. By cutting the power to the cell, the electrode will recover, but will again rise rapidly when power is restored.

A different approach was made at this point. A slightly hydrophobic carbon electrode was prepared first. Then a platinum/Teflon catalytic surface was applied to the carbon surface. T-71 is an example.

Carbon Electrode.

Acetylinic Carbon	58 Percent
Teflon Suspension	42 Percent

One cc of toluene was added to the above and the blend was mixed. The paste was spread on a Teflon-backed screen, dried at room temperature, and rolled until a porous, slightly hydrophobic film was obtained.

Platinum Electrode.

Black Platinum	50 Percent
Teflon Suspension	50 Percent

One cc of toluene was added to the above and, after mixing, the paste was spread on the carbon surface, dried at room temperature, and washed with distilled water. The

finished electrode was installed in the laboratory electrolysis unit. Results are shown on Fig. 2-10. The platinum loading was 22 mg Pt/cm^2.

This electrode compared quite favorably with some of the better commercial electrodes. At the end of 294 hr, the cell voltage had risen from 2.04 to 2.39 V, and the oxygen voltage had risen from 1.6 to 2.18 V.

T-72 and T-119 (Fig. 2-10) are examples of electrodes prepared in this manner. Catalytic loads are 25 and 30 mg/cm^2 Pt, respectively.

Figure 2-11 shows the laboratory performance of experimental electrodes that were used later in the one-man unit discussed below. These electrodes were all made from the same formulation in the same manner.

2.1.4.3 Large Electrodes for One-Man Unit

These electrodes were 90 cm^2. Two methods of preparation evolved from the work.

- A catalyst/Teflon/carbon paste is prepared and applied to a screen.
- A carbon electrode is prepared first and a catalyst/Teflon matrix is applied to the surface.

Screen Preparation. The screen was given a dilute sulfuric acid wash followed by a distilled water rinse. It was found that a micro-coat of Teflon on the screen improved the gas flow through the matrix as well as increased the adhesion of matrix to screen.

Treatment of Matrix. Rolling, pressing, and temperatures were kept to a minimum in order to combat the film-forming tendencies of Teflon.

Usable Formulations.

Teflon Suspension	40 to 60 Percent
Platinum Black	55 to 45 Percent
Acetylinic Carbon	10 Percent

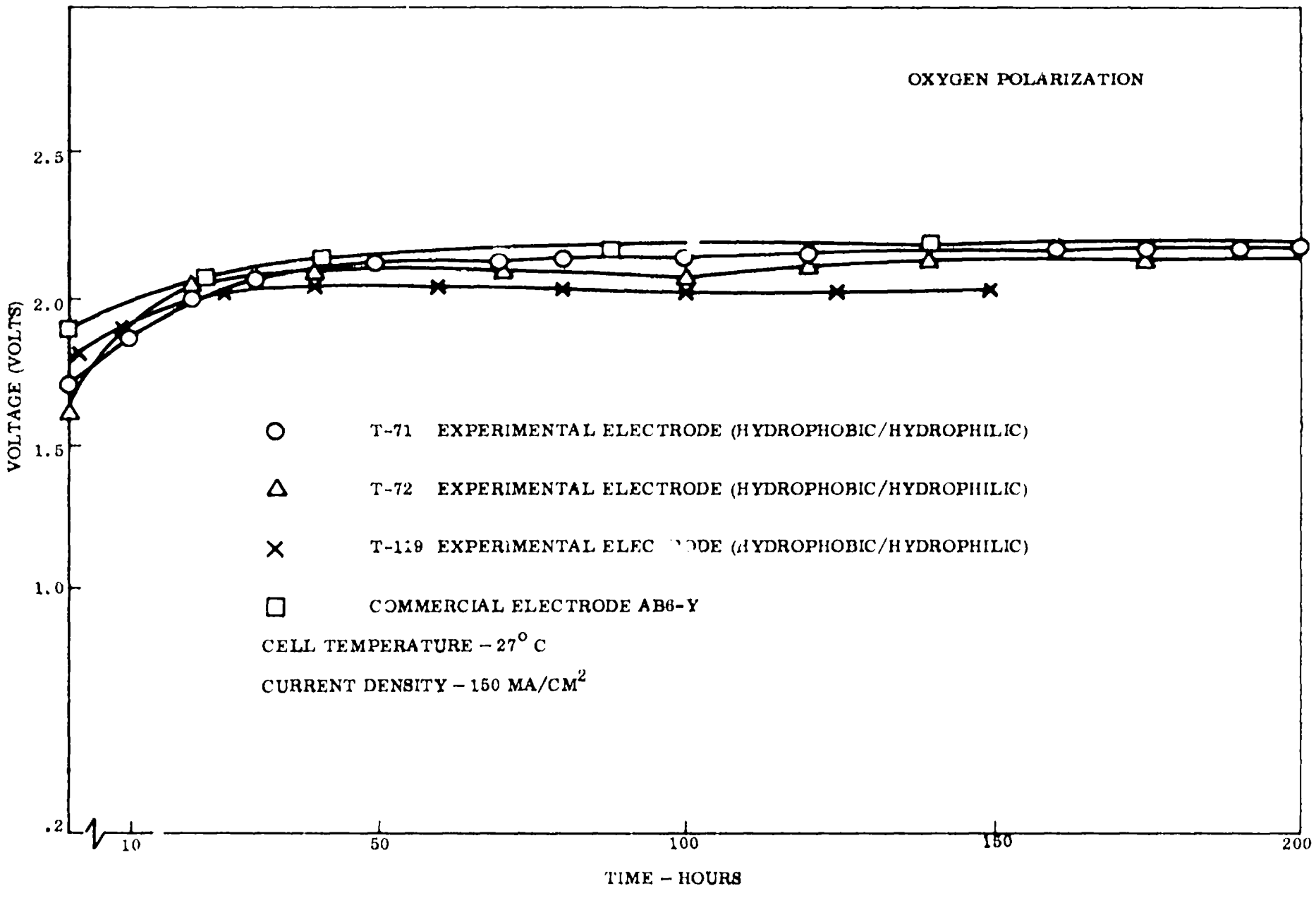


Fig. 2-10 Voltage vs. Time Curves for T-71, T-72, T-119, and a Commercial Electrode Assembly

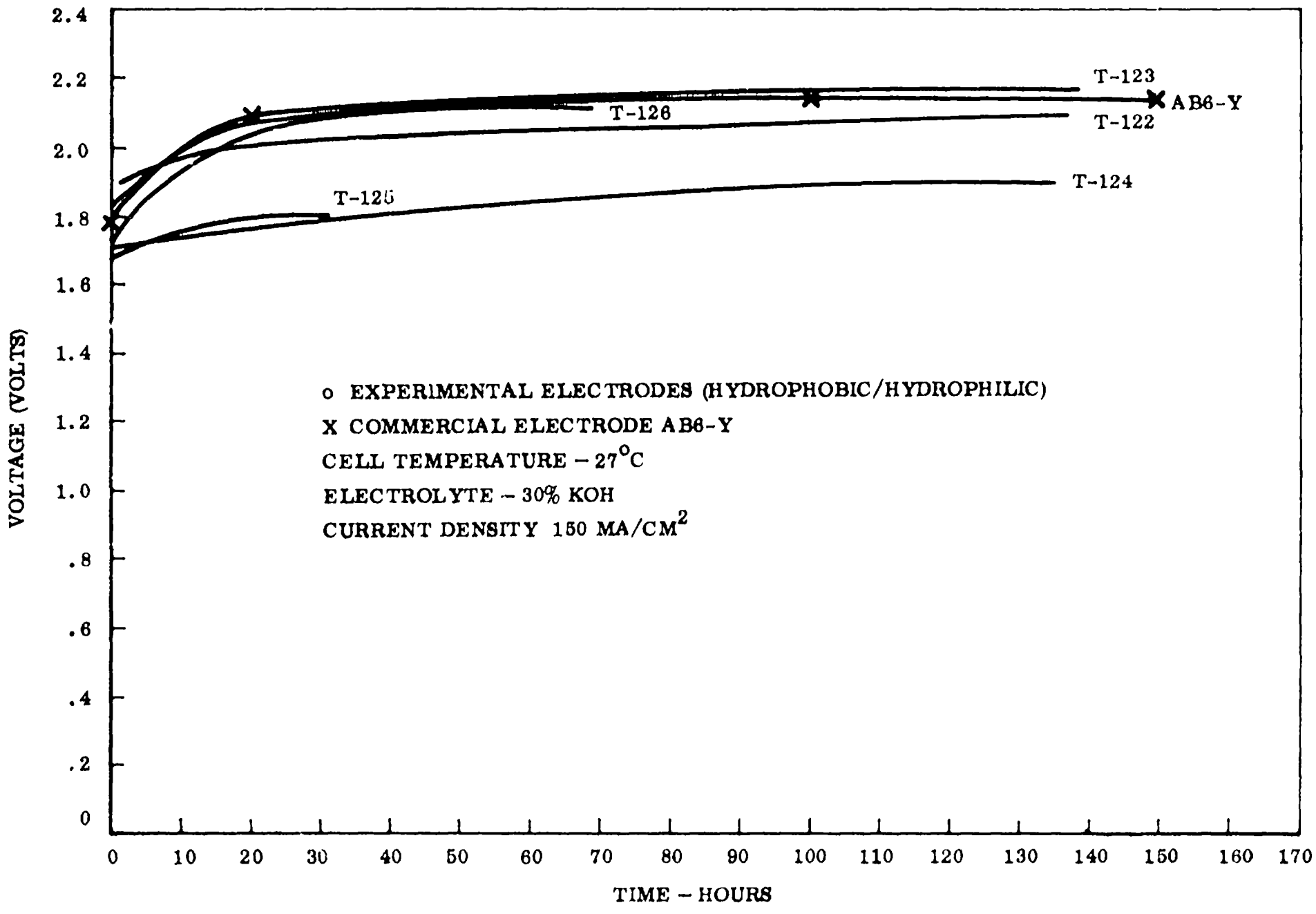


Fig. 2-11 Voltage vs. Time Curves for T-122 Through T-126

This mix, diluted slightly with toluene, can be applied to either a carbon/Teflon surface or a Teflon-backed screen. After drying at room temperature for 2 hr, the matrix can be rolled (calandered) four passes. It is a good idea to cover the surface with a thin polyethylene or wax paper sheet prior to rolling to prevent matrix pickup. Commercial wax paper was found to be satisfactory.

After the rolling operation, the matrix can be washed with toluene, dried at 100°C or less, and finally washed with distilled water.

Initial Performance Checks. Estimations of hydrophobic and hydrophilic properties can be made by dropping a drop of water on the surface. The water will remain a drop and will not wet a hydrophobic surface. A hydrophilic surface will wet, causing the drop of water to spread out. It is possible to make a rough estimation of contact angle and attending hydrophobicity or hydrophilicity of the catalytic surface.

The conductivity can be checked with a volt-ohmmeter. An interesting check on catalytic activity can be made by dropping one drop of methyl alcohol on a small portion of the electrode. A good electrode will cause the alcohol to burst into flame.

These various tests were used to provide a qualitative assessment of electrodes.

The final check is the installation of the electrode in the electrolysis unit. Figures 2-12, 2-13, and 2-14 show the electrical performance of three typical electrodes.

Analytical Work. Throughout the development period the purity of the oxygen generated by the experimental electrodes was monitored at various times by infrared and gas chromatographic analysis. No contaminants were detected.

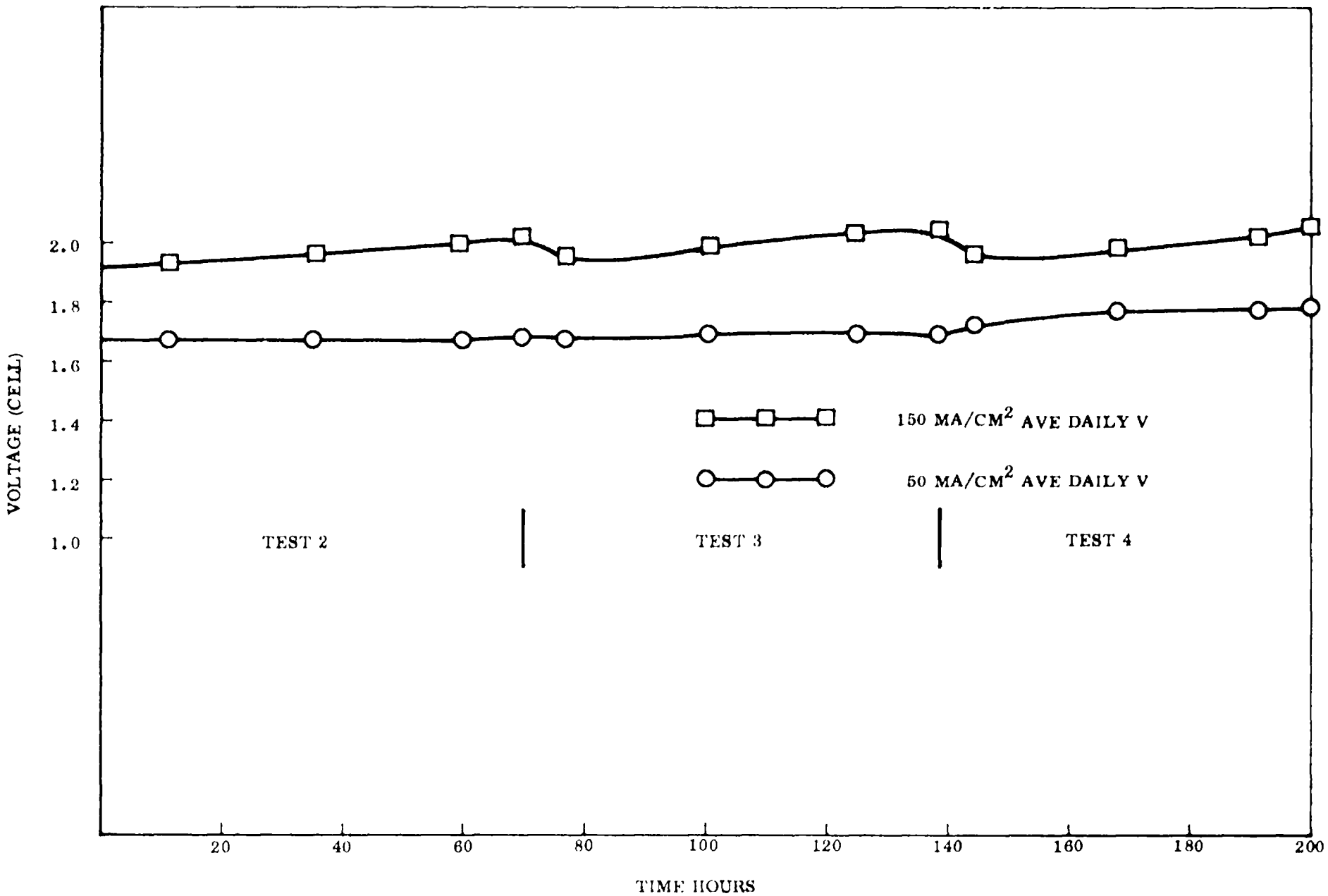


Fig. 2-12 T-124 Performance in O_2/N_2 System

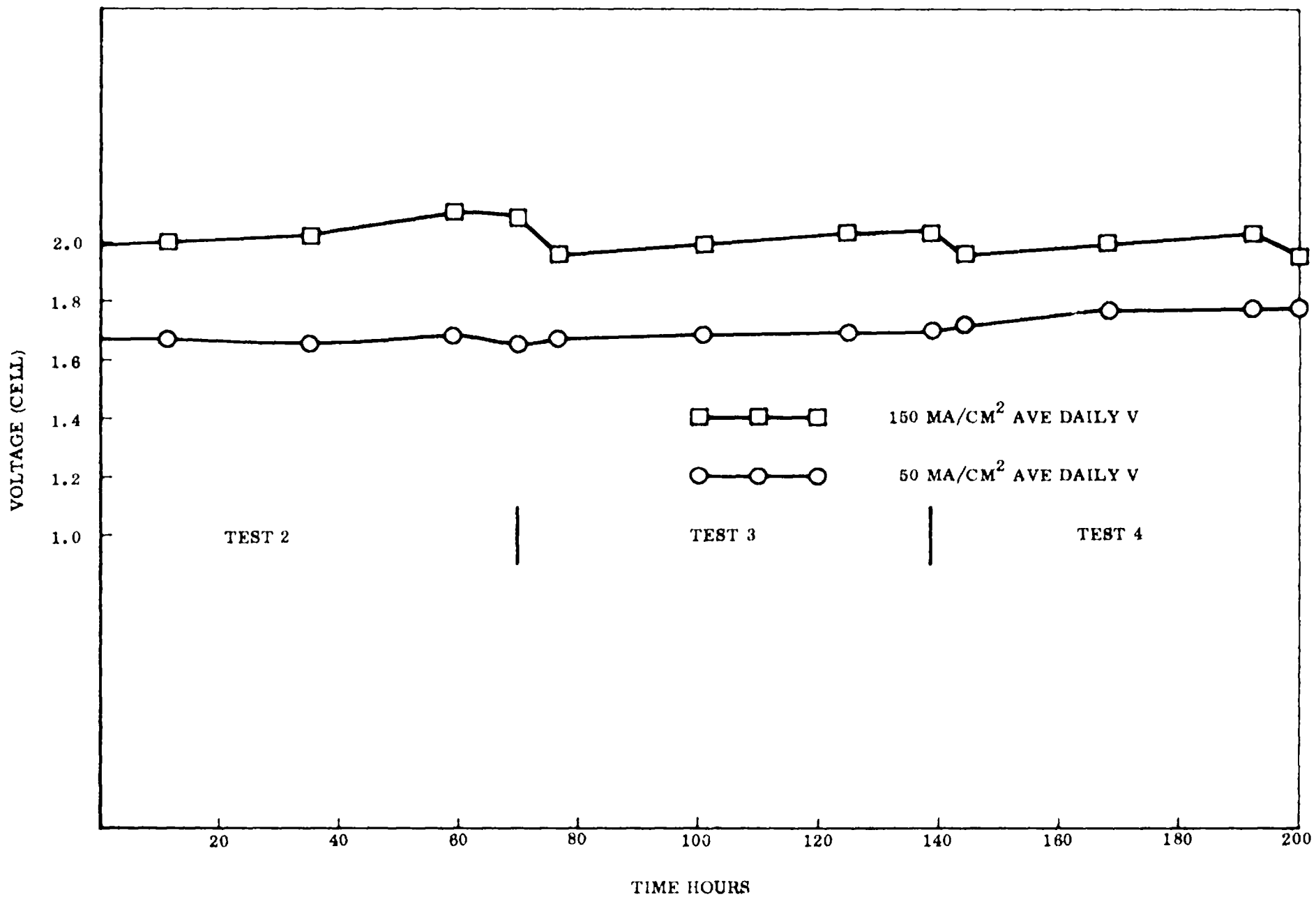


Fig. 2-13 T-125 Performance in O_2/N_2 System

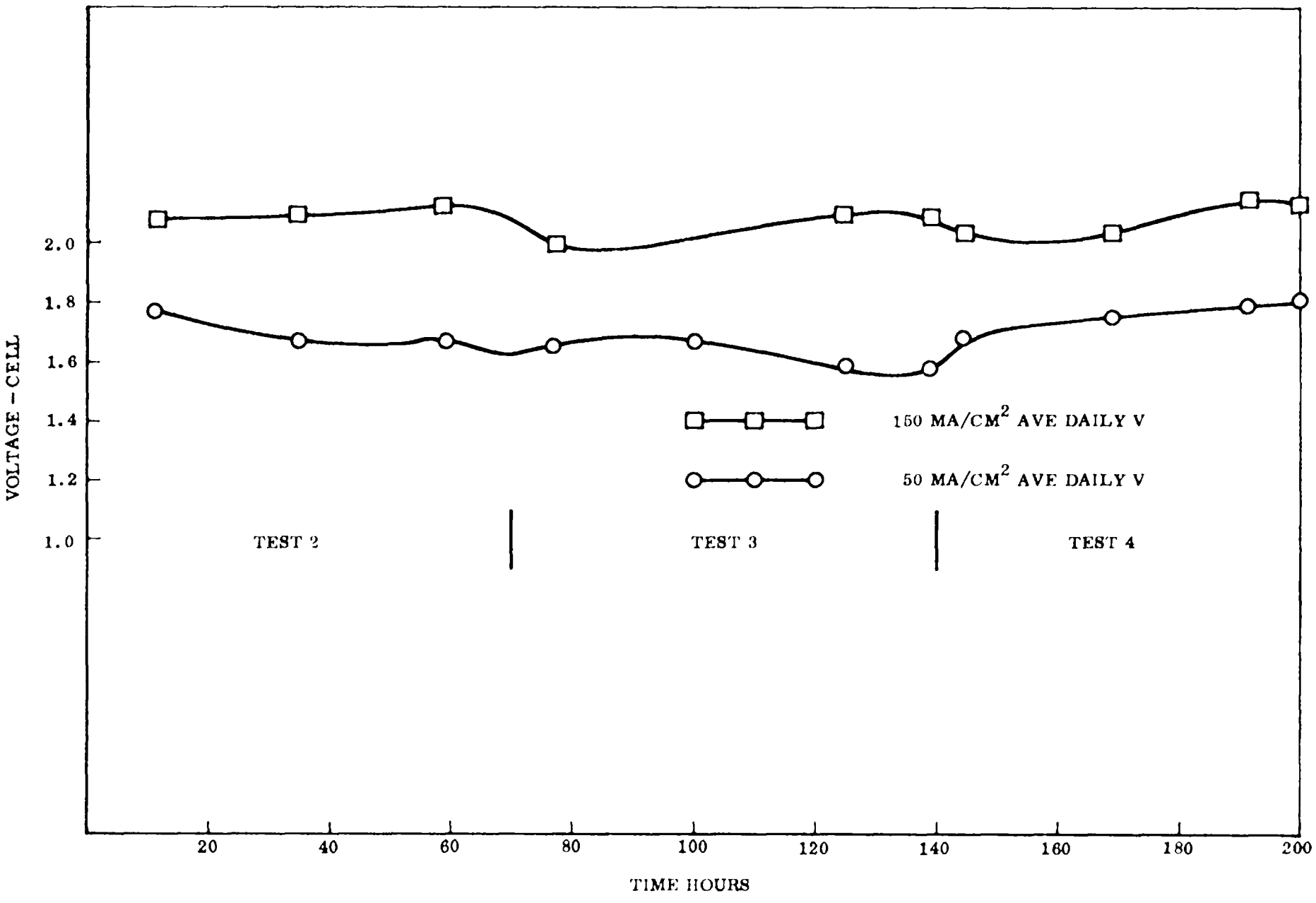


Fig. 2-14 T-126 Performance in O_2/N_2 System

2.2 ONE-MAN MODEL SYSTEM DESCRIPTION

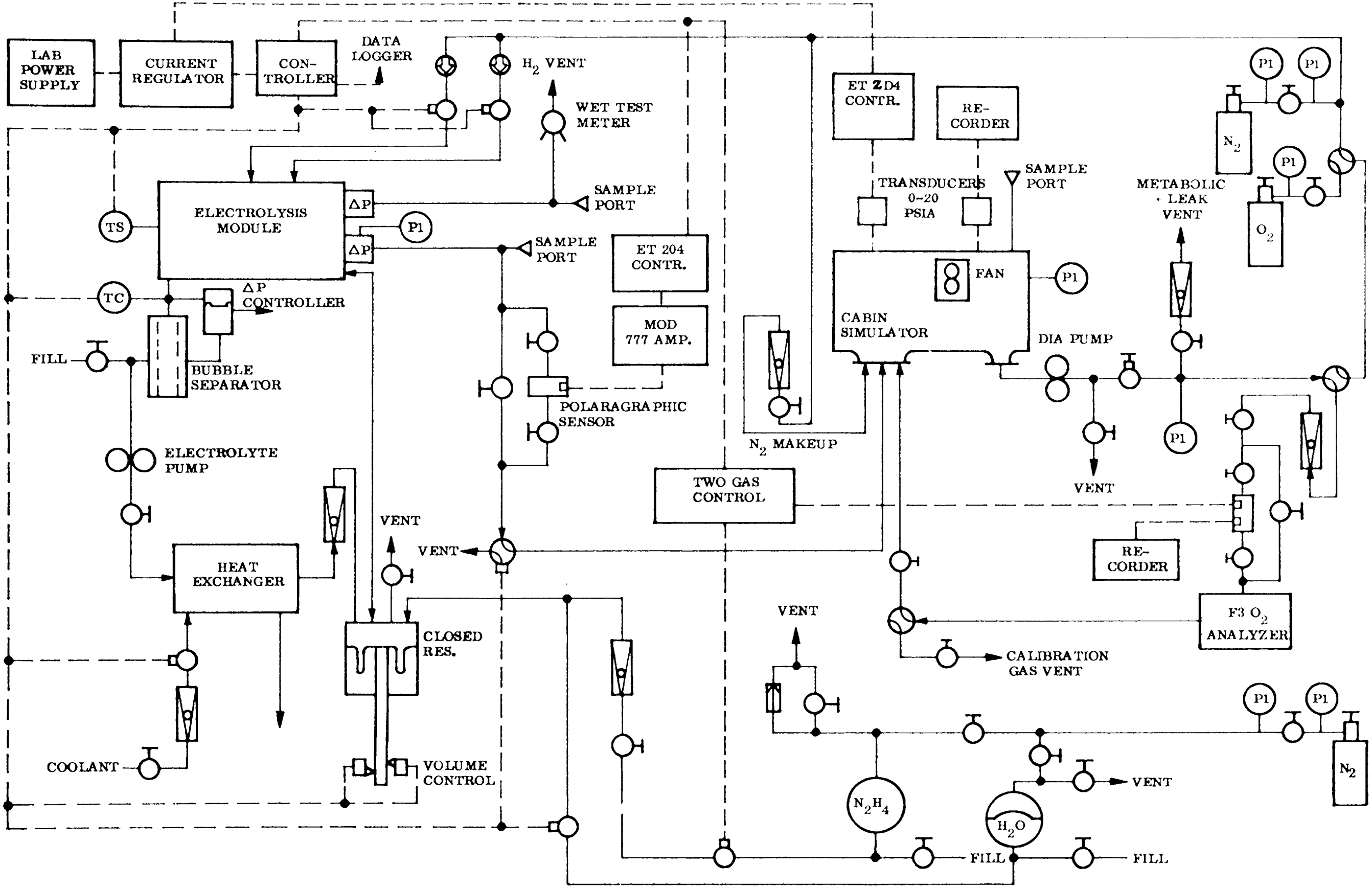
A laboratory breadboard hydrazine/water electrolysis system was assembled to provide a testbed for evaluating the oxygen/nitrogen generator technique. The gas generation system was sized to nominally provide a one-man metabolic supply and 1/12 of a space station cabin leakage makeup. This system was integrated with a cabin and metabolic/leak simulator and was instrumented to provide automatic control of the atmosphere in the cabin simulator. A schematic of this testbed is shown in Fig. 2-15.

2.2.1 Oxygen/Nitrogen Generation System

The oxygen/nitrogen generator consists of a closed-loop, liquid-electrolyte circulation system in which the gas generator, a stack of electrolysis cells, is operated in conjunction with accessories that provide for water and hydrazine feed, waste heat removal, differential pressure control, and bubble separation. Thirty percent potassium hydroxide is used as the electrolyte. Figure 2-16 shows the installed oxygen/nitrogen generation system. In this system, all surfaces in contact with the electrolyte, with the exceptions of the electrodes and matrix support screens, are composed of plastic.

Electrolysis Cell Stack. The electrolysis cell stack is comprised of 17 unit cells of the configuration shown in Fig. 2-17. The unit cell is designed so that liquid electrolyte flows through the center of the cell between two absorbent matrices contiguous to the operating electrodes. The matrices provide phase separation between the liquid in the center of the cell and the gases being generated on the open structure of the operating electrodes. Manifolds for the generated gases and the electrolyte are located on the periphery of the cell spacers; O-rings are used for sealing purposes. Cutaway views of the cell assembly are shown in Figs. 2-18 and 2-19.

The electrode assemblies consist of a rim, a spacer, support screens, an asbestos matrix, and an active electrode material. The rim is used for current take-off; a bent-over tab, which extends outside the cell, is used to interconnect electrodes in the stack of cells. The electrode spacer and support screen assembly is spotwelded to the rim and serves as a mechanical support and current distributor for the active material. The electrode consists of a mixture of black platinum catalyst and Teflon applied to a nickel screen substruct



2-29

Fig. 2-15 One-Man Model O_2/N_2 System Schematic

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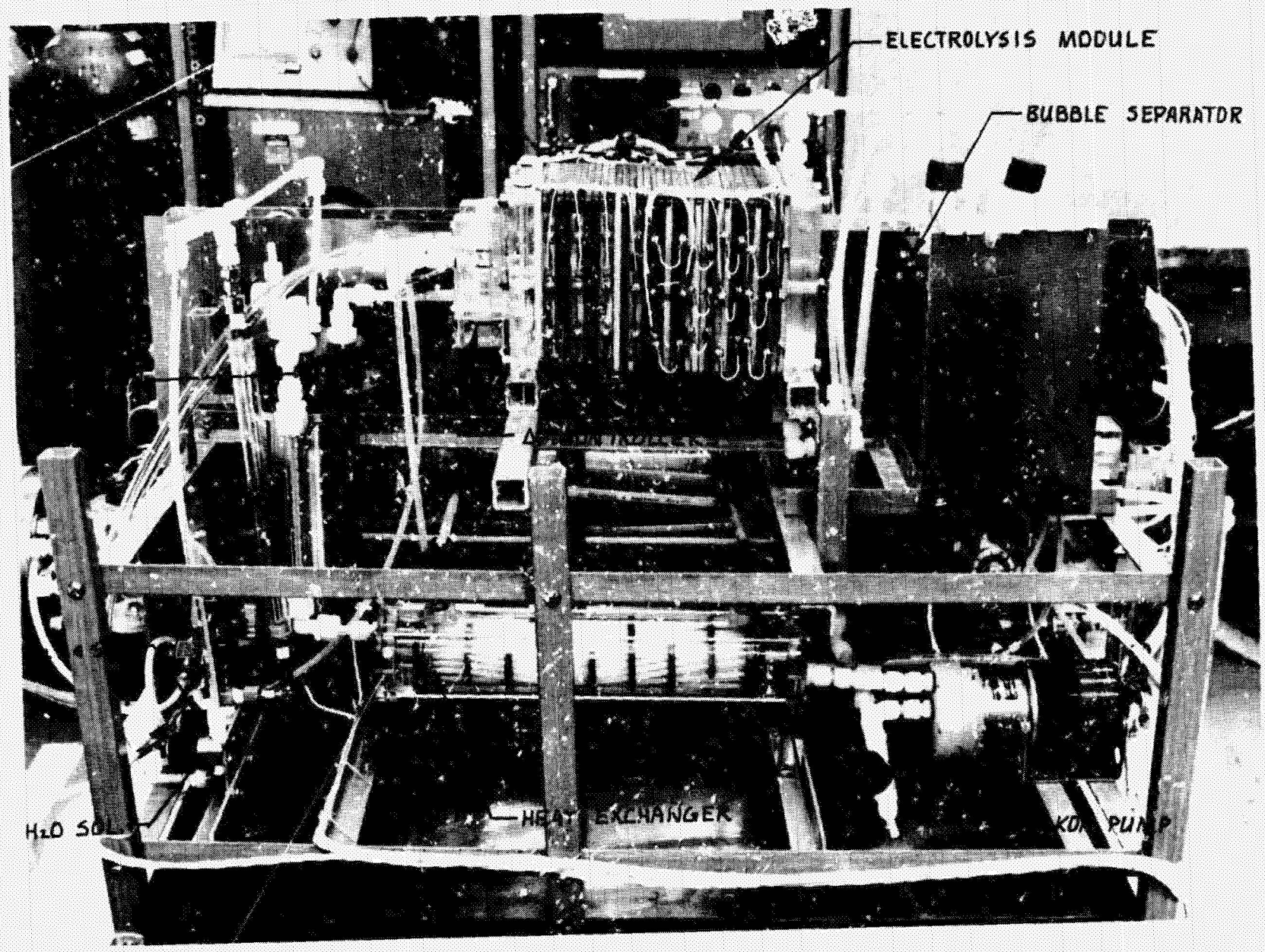
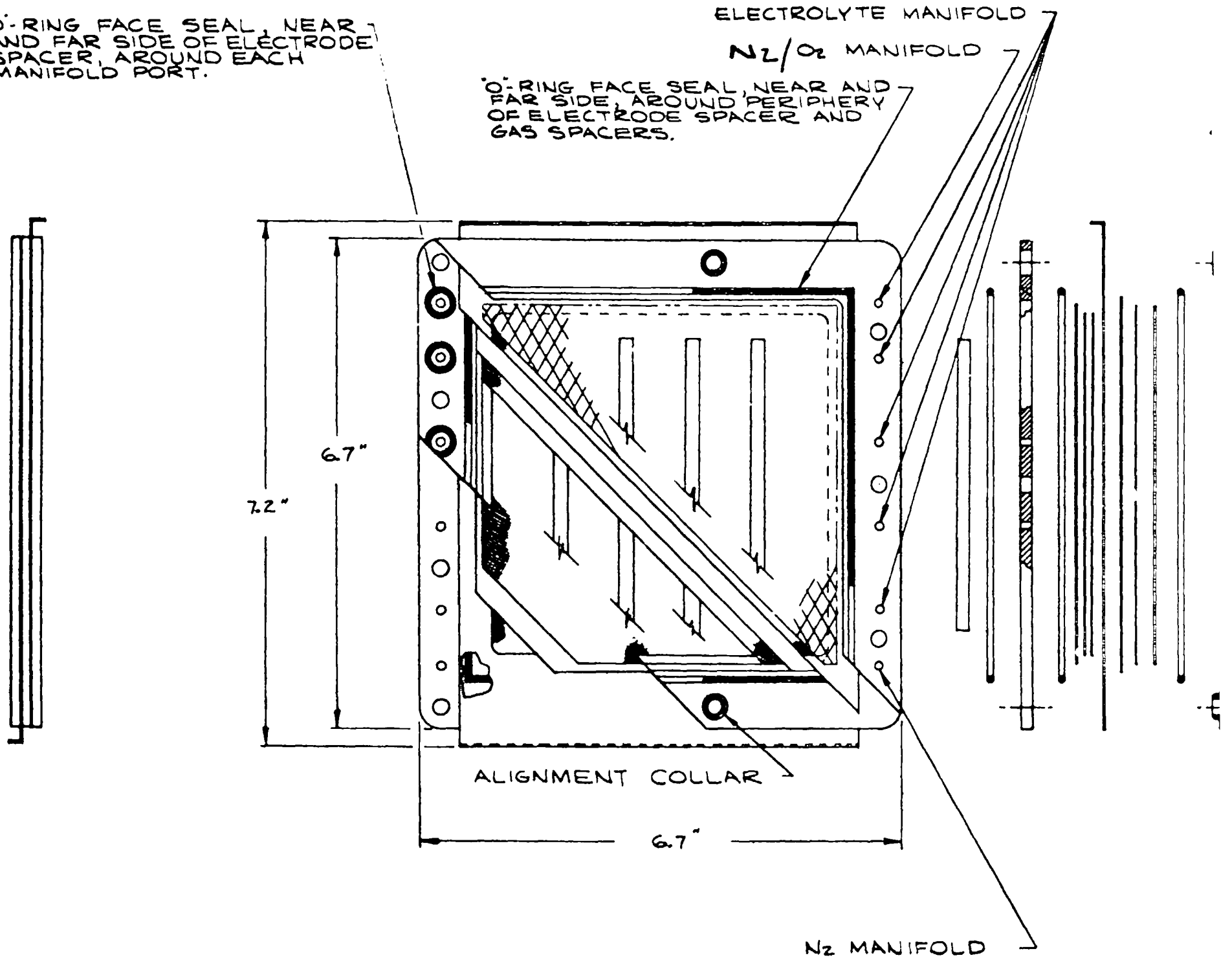


Fig. 2-16 O_2/N_2 Generation System



FOLDOUT FRAME 1

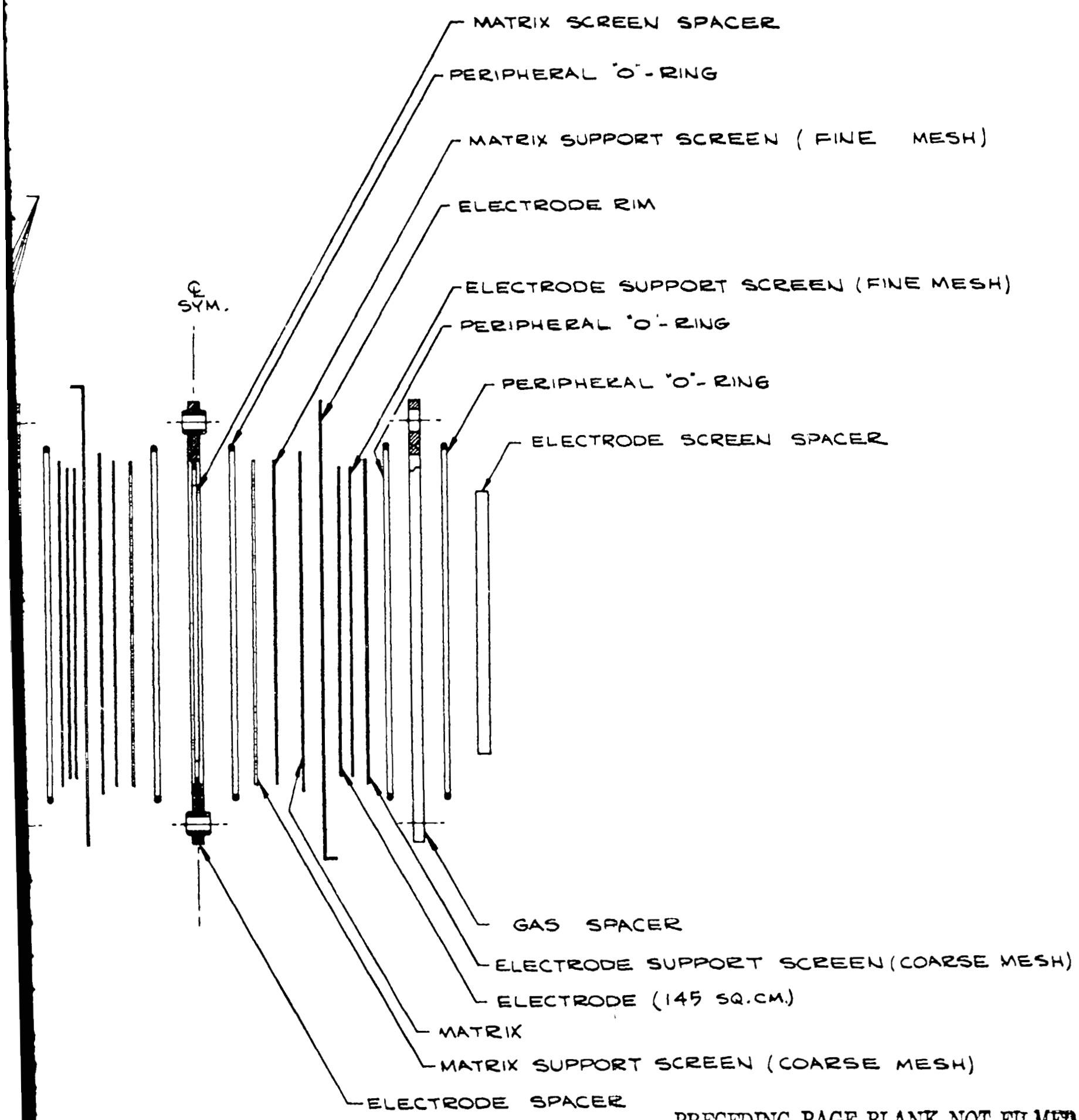


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Fig. 2-17 Cell Configuration

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FOLDOUT FRAME 2

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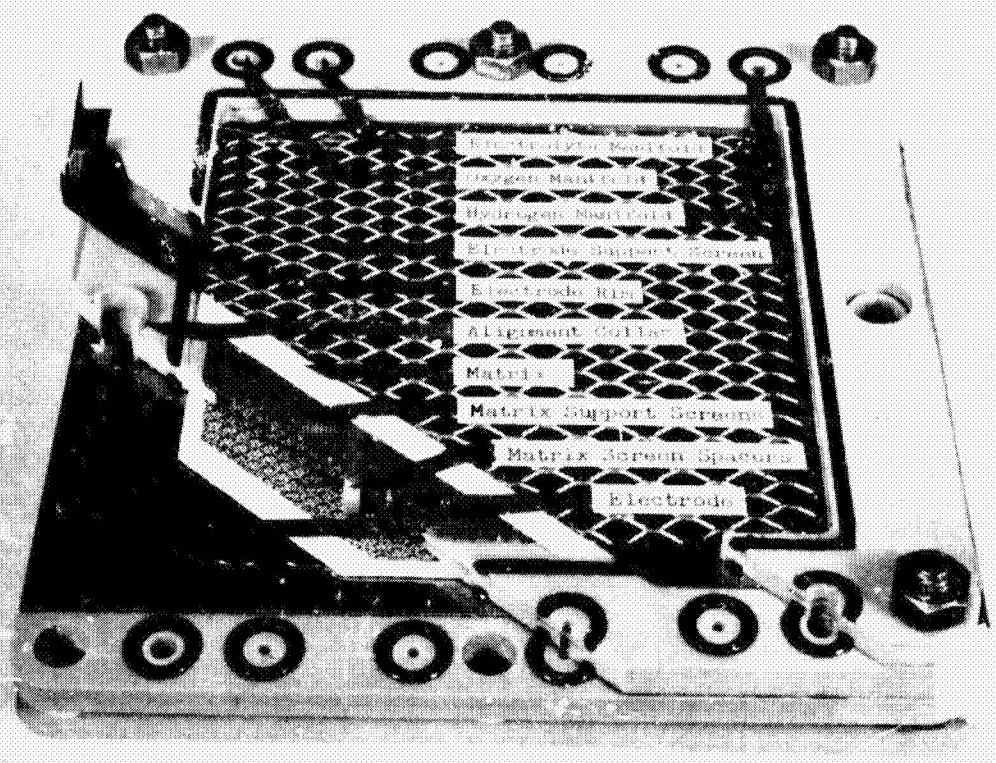

Fig. 2-18 Electrolysis Cell Cutaway View

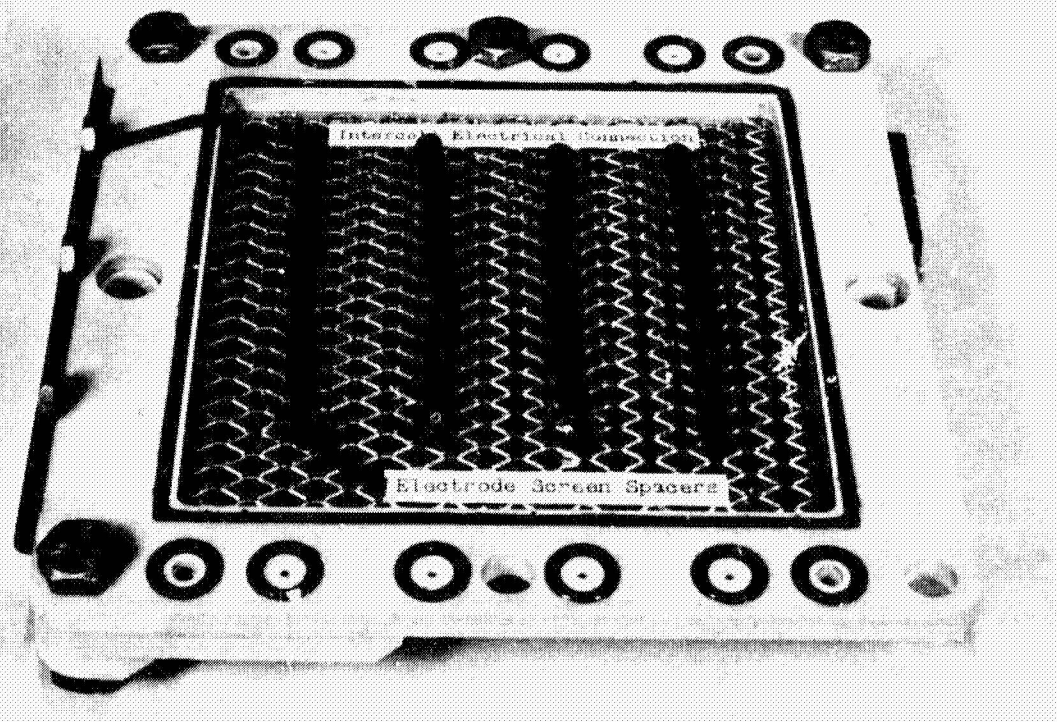

Fig. 2-19 Electrolysis Cell Reverse Side View

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The matrix material is a highly refined asbestos. It is held in place between the electrode structure and a set of nickel support screens. Epoxy spacers located in the electrolyte space hold the opposing matrix support screens apart. Resilient elastomer material is used for pressure strips on the gas side of the electrode to ensure uniform contact between the matrix and the electrode. These strips also act as springs in the stack of cells to take up tolerances in the assembly.

The cells are arranged in the stack in a cathode-anode-anode arrangement so that each internal gas spacer serves two adjacent cells. This reduces the cell spacer components required per cell (except for one end cell) to one electrolyte and one gas spacer. When the stack of cells is being assembled, alignment collars on the electrolyte spacers key the cell parts in the proper position and prevent misalignment.

The 17 cells in the stack are connected hydraulically in parallel and electrically in two series banks of eight and nine cells.

Heat generated by the electrolysis reaction is removed from the cell with the circulating electrolyte. By removing the heat in the external loop of the circulation system, close control of cell temperature can be maintained. This permits control of the dewpoints of the effluent gases below ambient, and thereby eliminates the problem of water condensation in gas lines, reservoirs, and valves downstream of the cell.

Water and N_2H_4 consumed in the electrolysis reaction in the cell are replaced by direct injection of the proper liquid in the external electrolyte circulation loop. This method of makeup is conducive to rapid electrolyte equilibration even at high operating currents.

Differential Pressure Controllers. Two differential pressure controllers are mounted directly on one end plate of the cell stack. These devices sense the electrolyte pressure in the cell stack and throttle the hydrogen and oxygen/nitrogen effluent gases to provide 25 in. of water differential pressure, gas-over-liquid. When gases are not being generated in the cell stack, nitrogen purge solenoid valves open to provide gas

pressure. This differential pressure control is required to maintain the gas/liquid interface at the electrodes. The differential pressure controller assembly is shown in Fig. 2-20.

Bubble Separator. A bubble separator is located downstream of the cell stack in the electrolyte circulation loop, as shown in Fig. 2-15. The function of this device is to remove gas from the circulating electrolyte. The source of this gas is primarily dissolved gas in the feed water which is freed in the gaseous phase as water is consumed in the electrolysis reaction.

The bubble separator consists of hydrophobic and hydrophilic membranes assembled in a configuration, shown in Fig. 2-21, in which liquid can flow only through the hydrophilic membrane, and gas can flow only through the hydrophobic membrane. The gas side of the separator is vented through a differential pressure controller. This ΔP controller is reverse-acting to the cell stack ΔP controllers and is used to maintain the liquid pressure across the hydrophobic membrane higher than the gas pressure.

Electrolyte Pump. A pump is used to circulate the electrolyte. It is a commercial laboratory model consisting of a centrifugal impeller assembly which is driven with a magnetic coupling. All surfaces in the pump which contact the electrolyte are plastic.

Heat Exchanger. Waste heat generated in the cell stack is removed from the electrolyte, external to the cell stack, in a heat exchanger. The heat exchanger is a laboratory model shell-and-tube type device constructed entirely of plastic. Coolant is admitted to the shell side and electrolyte flows through the tube side.

Closed Reservoir. The reservoir is a variable-volume device designed for zero-gravity operation which is used to maintain system pressure. The configuration of this device is shown in Fig. 2-22. A rolling diaphragm works against a spring-loaded piston to maintain the pressure in the electrolyte circulation loop. Volume changes due to the water and hydrazine feed cycles are thus absorbed in the reservoir chamber.

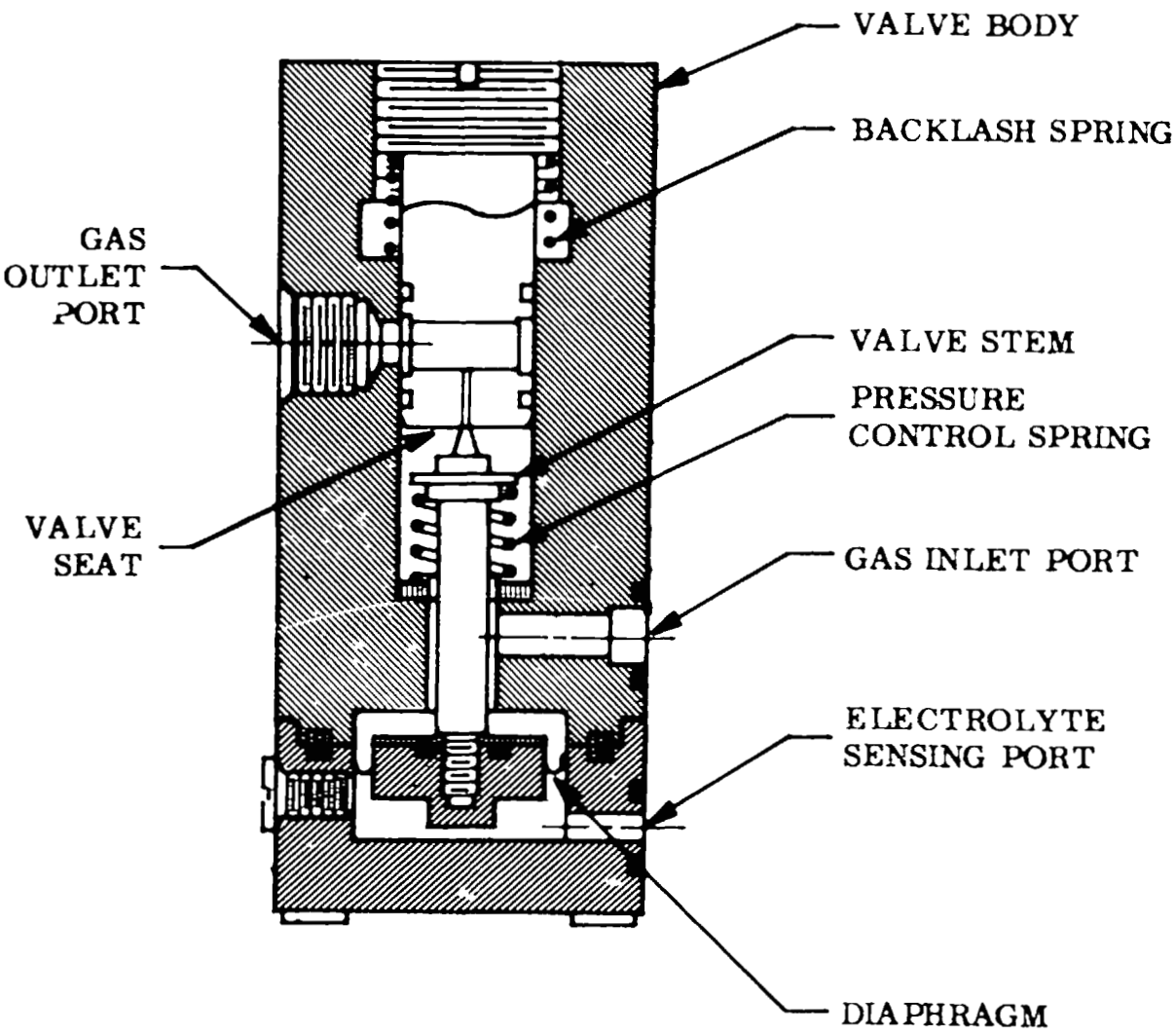

Fig. 2-20 Differential Pressure Controller Assembly

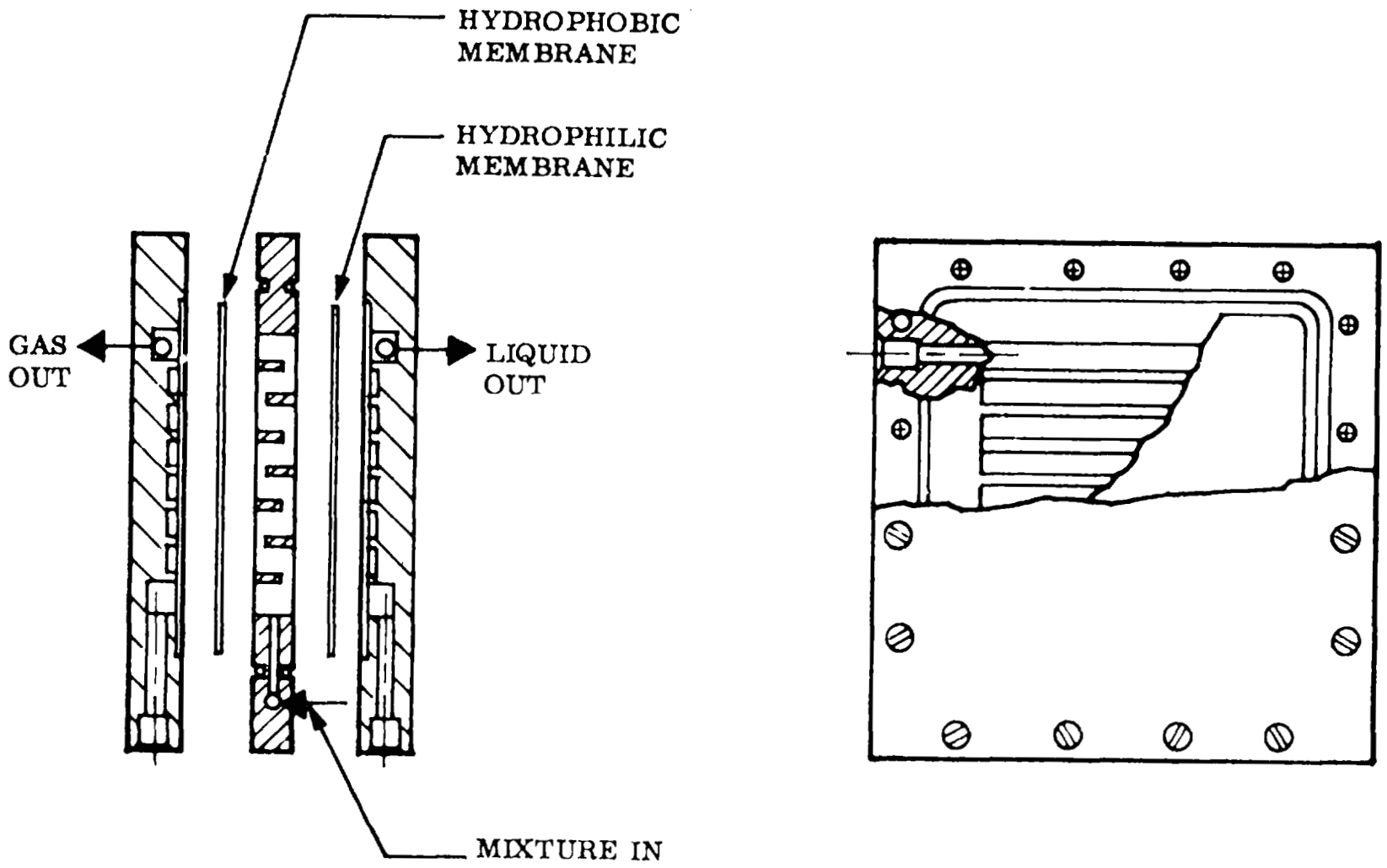

Fig. 2-21 Bubble Separator Configuration

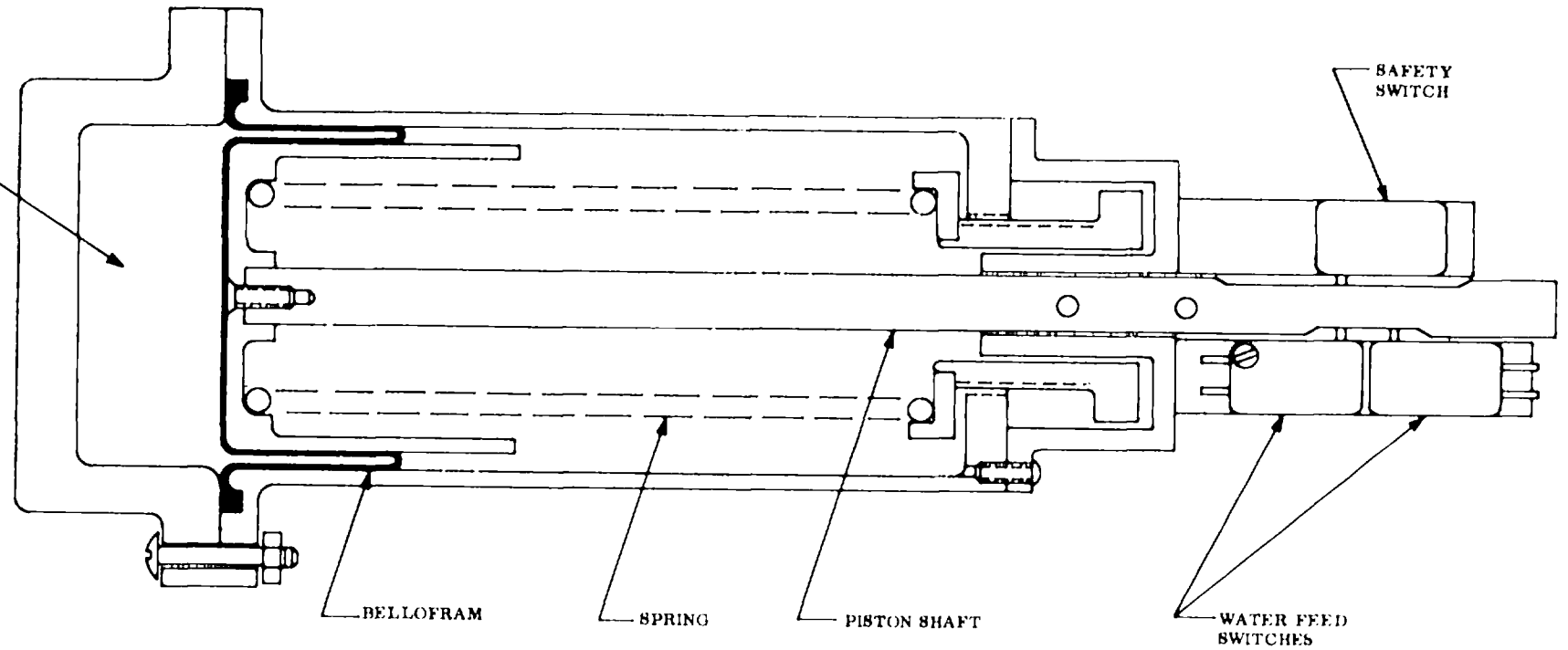

Fig. 2-22 Closed Reservoir Configuration

The position of the piston shaft is utilized to control the water feed; this control technique and the function of the safety switch are described in detail in Section 2.2.3.

Water and Hydrazine Storage. Spherical storage tanks for water and hydrazine are mounted underneath the oxygen/nitrogen generator. The water tank contains a silicone rubber bladder, and nitrogen gas pressure is applied to the back side of the bladder. When water feed is required, a solenoid valve opens in the water feed line, allowing the nitrogen pressure to force water into the closed reservoir. The hydrazine is stored in a similar tank from which the bladder was removed.* It is mounted so that nitrogen pressure is applied at the top and hydrazine is withdrawn at the bottom of the tank. As with the water feed, a solenoid valve opens to allow hydrazine to enter the closed reservoir. A micrometer valve and flowmeter are provided to set the hydrazine flow rate. The plumbing required to permit filling, draining, and pressurization of these tanks is shown in Fig. 2-15.

2.2.2 Cabin and Metabolic/Leak Simulator

The tank shown in Fig. 2-23 is used as a cabin simulator. It is equipped with gasket-sealed ports, an O-ring sealed door, and has a rotary fan mounted inside to assure gas-mixing. It was designed to be suitable for both vacuum and pressure applications. The volume of the tank is 30 cu ft.

The cabin simulator is integrated with the oxygen/nitrogen generation system and a metabolic/leak simulator system. It has, as well, an external sampling loop through which cabin gas is continuously circulated.

Metabolic/Leak Simulation. Metabolic consumption of oxygen and cabin leakage of oxygen and nitrogen are simulated by withdrawing gas from the cabin simulator at a controlled rate. Because oxygen cannot be withdrawn preferentially from the cabin,

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*The bladder material, silicone rubber, is not compatible with hydrazine. A suitable [illegible] ethylene propylene, required a special order, and delivery time was not [illegible] the program schedule.

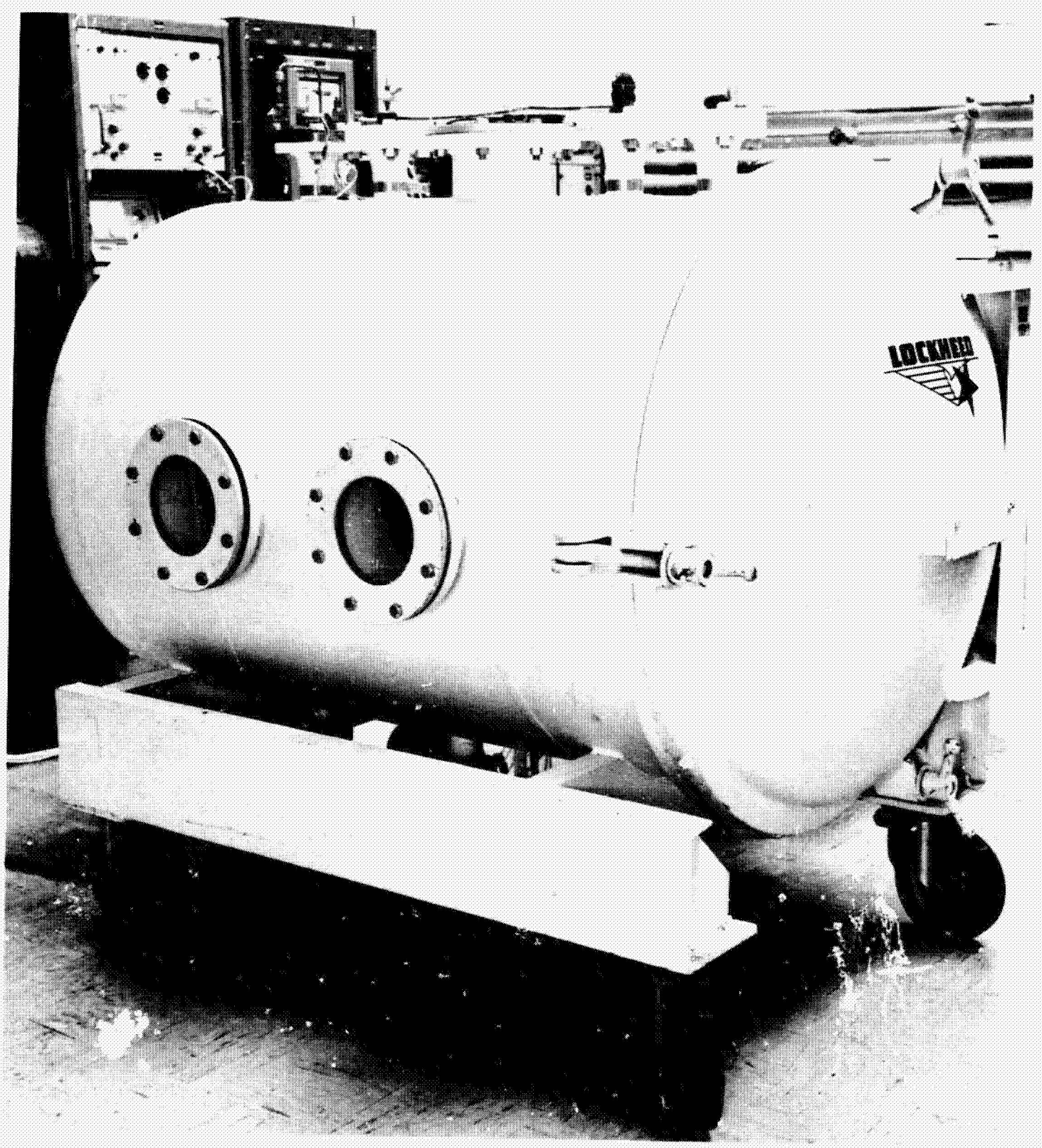


Fig. 2-23 Cabin Simulator

the total amount of gas removed includes the metabolic and leakage oxygen, the leakage nitrogen, and an amount of excess nitrogen removed with the metabolic oxygen. A controlled amount of nitrogen is replaced in the cabin simulator as makeup for excess nitrogen removed with the metabolic oxygen. The flow control valve and flowmeter configuration used to accomplish this metabolic/leak simulation is shown in Fig. 2-15.

Cabin Atmosphere Sampling Loop. The cabin simulator is operated below ambient pressure at approximately 12 psia. In order to remove the metabolic/leak gas, a diaphragm pump is used to raise the pressure in a sampling loop outside the cabin to a pressure above ambient. A nonrelieving pressure regulator is used to control the pressure in this loop. Cabin gas is continuously circulated through the loop for gas composition monitoring. Provision also is made for introducing calibration gases in the portion of the sampling loop containing the gas-monitoring sensors.

2.2.3 Instrumentation

The model system is instrumented with automatic controls of the oxygen-nitrogen generator functions, cabin atmosphere control, power conditioning and both digital and analog readouts of system parameters.

All control logic and power conditioning are handled with solid-state circuitry. The system is also equipped with automatic safety circuits which will cause complete system shutdown if unsafe conditions occur. A block diagram of the system instrumentation is shown in Fig. 2-24. Detailed circuit diagrams are included in Appendix A.

2.2.3.1 System Controls and Safety

Water balance in the electrolyte loop is maintained by controlling the electrolyte volume. A set of microswitches turn the water feed solenoid valve on and off as the piston in the closed reservoir moves up and down. The movement of the piston shaft and the actuation

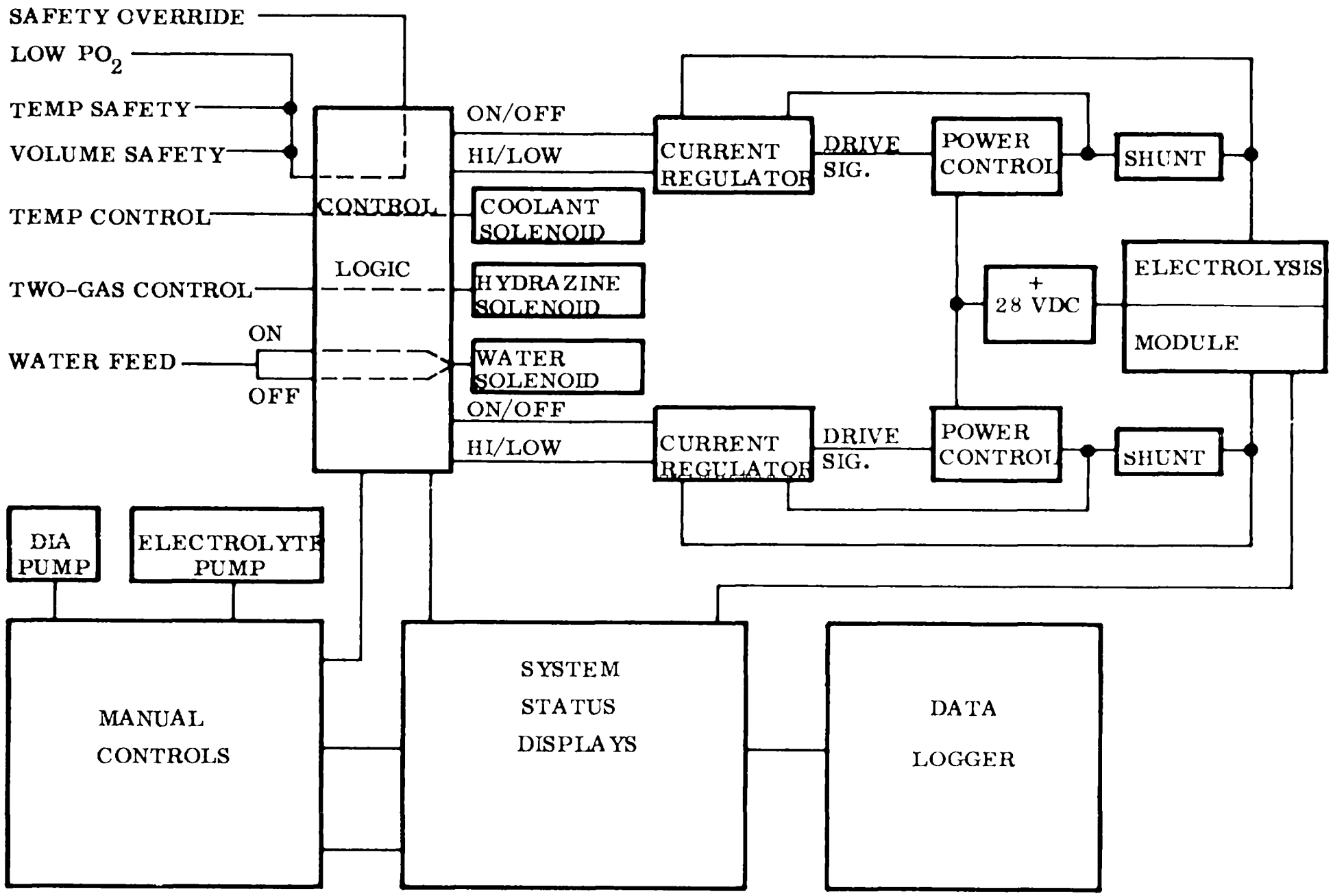


Fig. 2-24 O_2/N_2 System Control Block Diagram

of the microswitches by a detent in the shaft that occurs during a water feed cycle is shown in Fig. 2-25. In position (a), the piston is in the middle of the water feed control band. As water is consumed in the electrolysis reaction, the electrolyte volume shrinks and the piston travels upward to position (b). Here the lower microswitch closes and signals the water feed solenoid to open. As water feed continues, the piston travels down through position (c) and continues to position (d), where closure of the upper microswitch signals water feed shutoff. The cycle described in this figure is completed as the piston returns to its starting position at (e).

The piston travels approximately 3/8 in. during a water feed cycle with a corresponding volume change of about 45 cc.

The control logic is such that water feed is commanded off whenever both microswitches are actuated, as would be the case if the piston shaft detent is completely above or below both switches. A manual override is provided so that the operator can command the water feed either on or off at any time.

Control of the electrolyte temperature, necessary because of the waste heat generated in the electrolysis reaction, is accomplished by using a thermoswitch in the electrolyte discharge from the cell stack to provide a control signal to a coolant solenoid valve. On demand, the solenoid valve opens to allow coolant (ethylene-glycol) to flow through the electrolyte heat exchanger. The flow rate is set with a flow control valve. Control of the electrolyte temperature also provides control of the dewpoints of the generated gases. The thermoswitch used in this system has a switch-closure setting of 75°F.

On-off control is provided for the hydrazine feed. A polaragraphic oxygen partial pressure sensor in the cabin simulator sampling loop provides the signal to the hydrazine-feed solenoid valve. When cabin PO_2 reaches an adjustable upper set point, the hydrazine solenoid opens to admit flow to the closed reservoir. The solenoid valve remains open until cabin PO_2 reaches an adjustable lower set point. A manual micrometer valve and flowmeter can be used to set the hydrazine flow rate during the

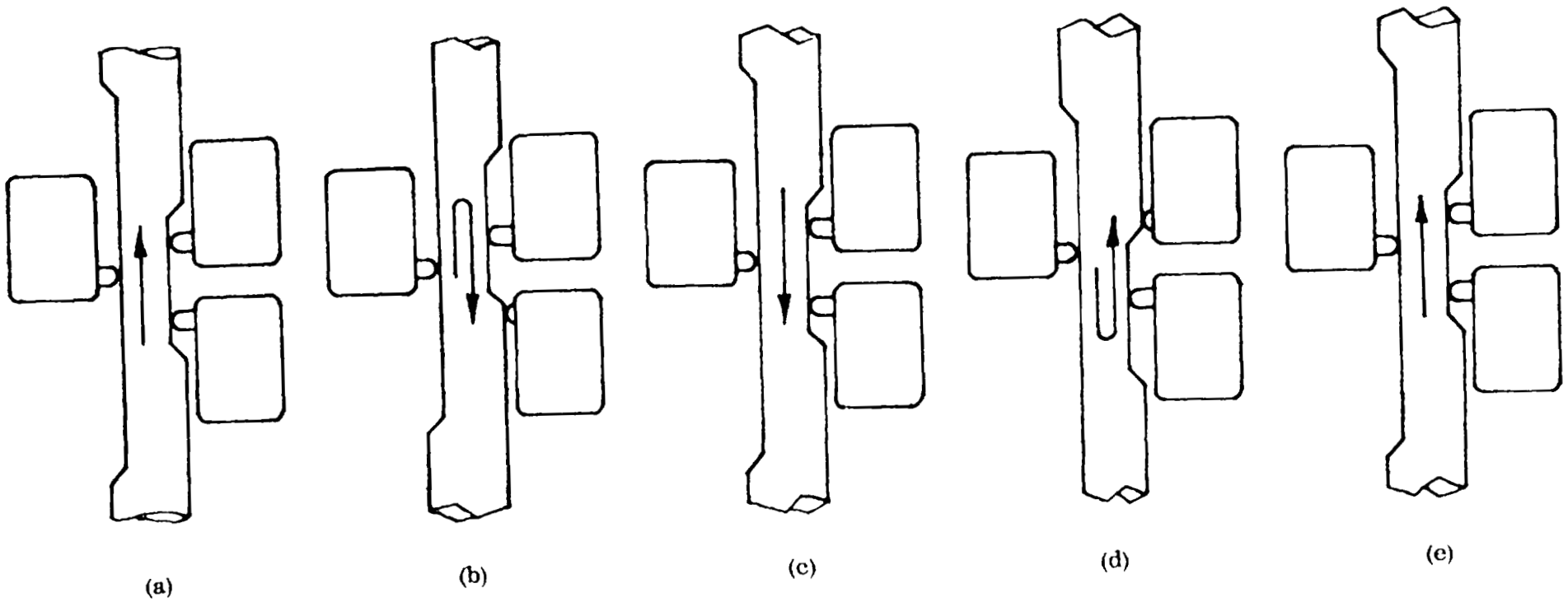


Fig. 2-25 Water Feed Control Mechanism

on portion of the feed cycle. Manual override is provided so that hydrazine can be commanded on or off at any time.

The electrolysis cell stack current control utilizes a high/low mode of operation. Both the high and low current values are adjustable. A signal from a pressure transducer is used to control the current mode. When the cabin total pressure (P_T) reaches an adjustable upper limit, the current is commanded to the low mode. The low mode is maintained until P_T reaches an adjustable lower set point; the current then switches back to the high mode. Manual override is provided so that the current mode can be commanded low, high, or off at any time.

In order to minimize the operating temperature of solenoid valves used in this system, a holding-current technique is employed. Whenever a signal to energize a solenoid valve coil occurs, a brief actuation current pulse is provided and then the current is reduced to a holding level. Power dissipation with this holding current is sufficiently low so that the solenoid valve bodies remain essentially at ambient temperature. This approach is especially useful for solenoid valves that remain energized closed for long periods, and increases the operating life of the valve seals.

Sensors and circuit logic are provided to effect automatic shutdown of the system in the event of an unsafe or abnormal operating condition. The shutdown logic, when actuated by a safety sensor signal, disables the electrolyte pump, turns off the water and hydrazine feed, opens the N_2 purge solenoid valves to purge the H_2 and O_2/N_2 chambers of the cell stack, and diverts the O_2/N_2 module effluent from the cabin simulator to a fume hood.

One of the safety sensors is located on the closed reservoir. Recalling that the water feed control utilizes a set of microswitches which operate on a detent on one side of the reservoir piston shaft, a similar detent and associated microswitch on the opposite side of the piston shaft provide a high or low reservoir volume signal. The safety switch is set to actuate ± 150 cc on either side of the water feed control band. High-volume shutdown would occur in the event of overfeed of water or hydrazine. Low-

volume shutdown would occur in the event of lack of water feed or a leak in the electrolyte loop.

Overtemperature protection is provided in the form of a thermoswitch mounted in one end plate of the cell stack in contact with an end electrode. This sensor is a two-position sensor that actuates a warning light at 85°F and an automatic system shutdown at 105°F. Overtemperature shutdown would occur in the event of coolant supply failure or electrolyte pump failure.

Protection against excessive hydrazine feed is provided by a polarographic PO_2 sensor in the cell stack O_2/N_2 effluent gas line. When an adjustable minimum effluent PO_2 set point is reached, the hydrazine feed solenoid valve is automatically shut off.

Power loss protection is provided. In the event of the failure or even momentary loss of plant power, the system will automatically shut down and will not restart after power has been restored until manually reset.

The system control and safety instrument panel is shown in Fig. 2-26. The lefthand side of the panel contains all of the electronic instrumentation; the center panel has the data logging signal leads; and the righthand side contains the flow controls for the cabin and metabolic/leak simulation.

Fault diagnosis is provided by the upper row of lights on the instrument panel, which can be seen in this figure. Indicators include temperature warning, overtemperature shutdown, high/low volume shutdown, and safety PO_2 shutoff of the hydrazine feed. The safety indicator that indicates the cause of automatic shutdown will remain on until the system is manually reset. All of the safety circuits contain logic to prevent the system from being reactivated automatically before the cause of the unsafe condition can be rectified.

A manual override of the safety circuits is provided and is used during system startup at the beginning of a test.

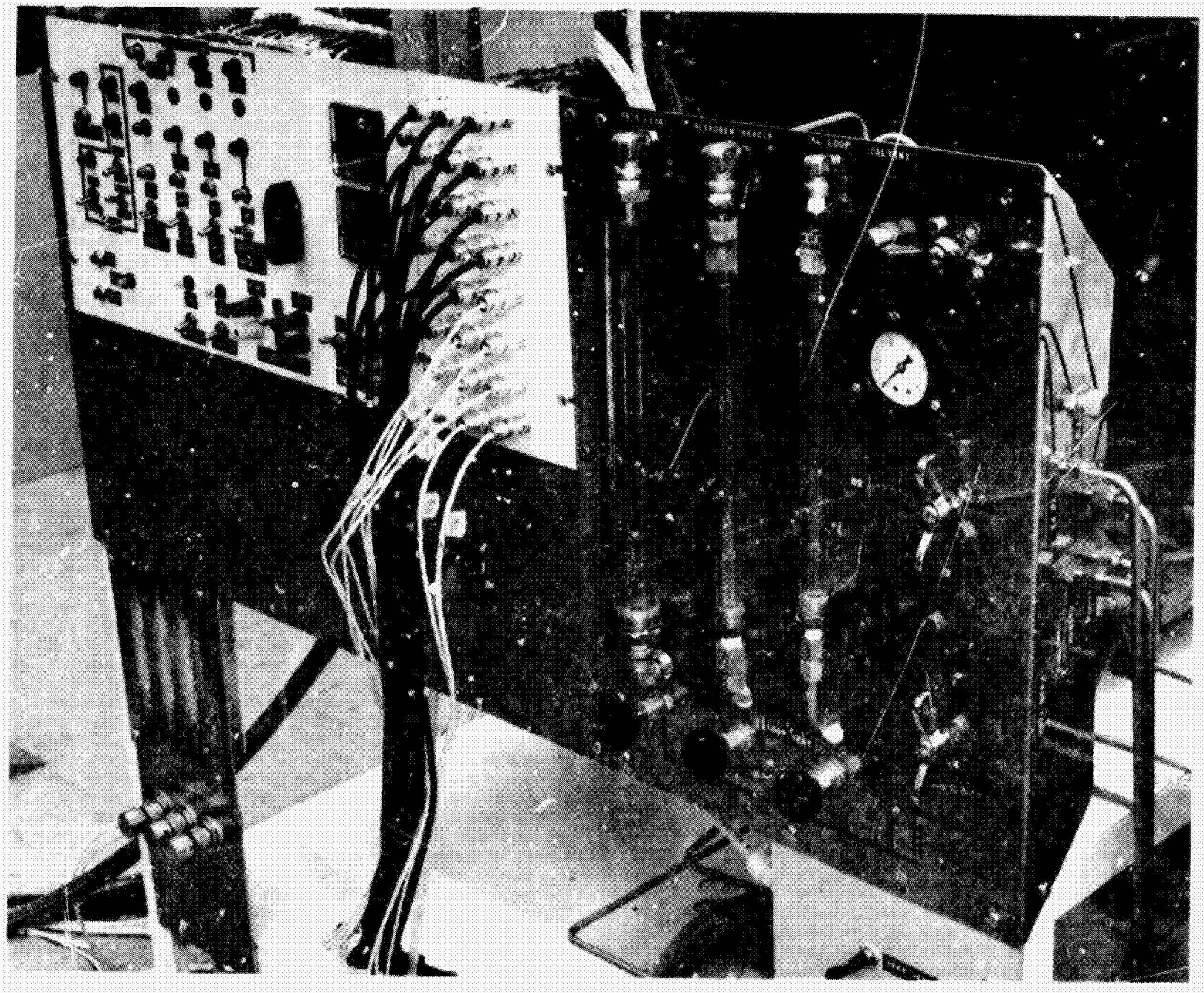


Fig. 2-26 O_2/N_2 System Control Panel

2.2.3.2 Power Conditioning

Conditioning and regulation of the power for the electrolysis cell stack is accomplished with high-efficiency programmable current-switching regulators. A pulsewidth-modulated signal drives a power-switching amplifier, which produces a constant current through the cell stack.

The 17-cell stack is divided into an eight- and nine-cell electrical bank. Each bank has its own current regulator, but shares outputs from the current mode controller and oscillator.

Figure 2-27 illustrates the technique employed to obtain this type of regulation. Load current is sampled via a differential voltage developed across the shunt resistor, R_S. This signal is amplified by the feedback amplifier and presented to the error amplifier where it is compared with a fixed reference signal. If a difference exists between the sampled signal and the reference signal, an error voltage will be developed and fed to the pulsewidth modulator. A fixed frequency (approximately 15 kHz) squarewave oscillator provides the trigger source for the pulsewidth modulator. The output of the modulator drives the switching transistor, Q.

The transistor serves as a switch and is either shut off or saturated. The length of time the transistor is "on" or saturated depends on the time length of the pulse emitted from the modulator. The operation of the circuit is divided into two cycles: first, when transistor Q is on; second, when Q is off.

During the interval when Q is on, a current path is provided from the positive side of the unregulated input source through inductor, L, shunt, R_S, the cell bank load, and through the transistor to the supply return. Switching diode, D, is back-biased during this interval; thus, no appreciable current flows through it. Capacitor, C, is allowed to charge to the cell bank voltage, thus storing energy. Since the voltage across the nonsaturating choke inductor, L, is constant, the current through the

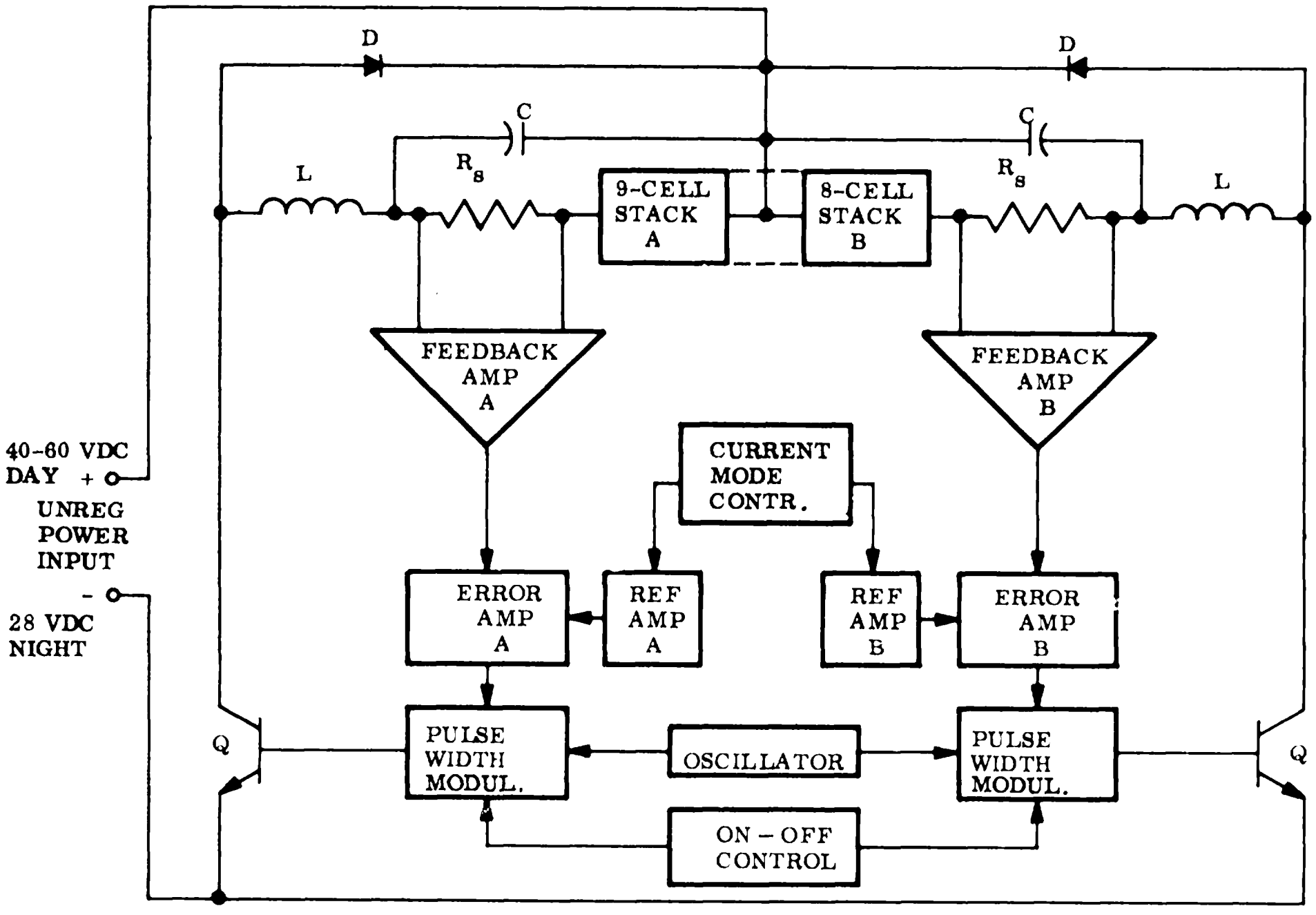


Fig. 2-27 Power Conditioning Technique

choke – which is also the shunt, load, and transistor current – will increase linearly with time according to $e_L = L\,di/dt$. When the average current through the shunt equals the reference signal current level, the error is decreased to zero and the modulator turns the switching transistor off, which triggers the second cycle of operation.

When the current source through the choke is inhibited by the transistor switch, the voltage across the choke immediately reverses due to the decreasing choke current, thus forward-biasing and turning on switching diode, D. At this point, the choke and capacitor start to release their stored energies, thus providing a current source through the diode to the cell-bank load for this half of the cycle. When the average load current falls below the reference current level, the transistor is switched on again via the pulsewidth-modulator/error amplifier, and the cycle repeats.

The load currents are programmed by varying the reference current signal level to obtain high- and low-mode currents.

The efficiency of this circuit is inherently high as compared with conventional series regulators because the power losses are minimized by saturating the switching transistors and diode when they are turned on and not allowing the choke to become saturated.

Current regulation components of this circuit are mounted on a circuit card which plugs in behind the control panel. High-current components are mounted on an air-cooled cold plate, which can be seen in Fig. 2-28.

2.2.3.3 Control and Monitoring Instrumentation

The model system is instrumented with the sensors required to provide signal inputs for the control, safety, and power conditioning circuits described above. In addition, sensors and readouts are utilized to provide system performance data. The sensing and readout techniques used in the system are given in Table 2-2. Some of the instrumentation is shown in Fig. 2-29.

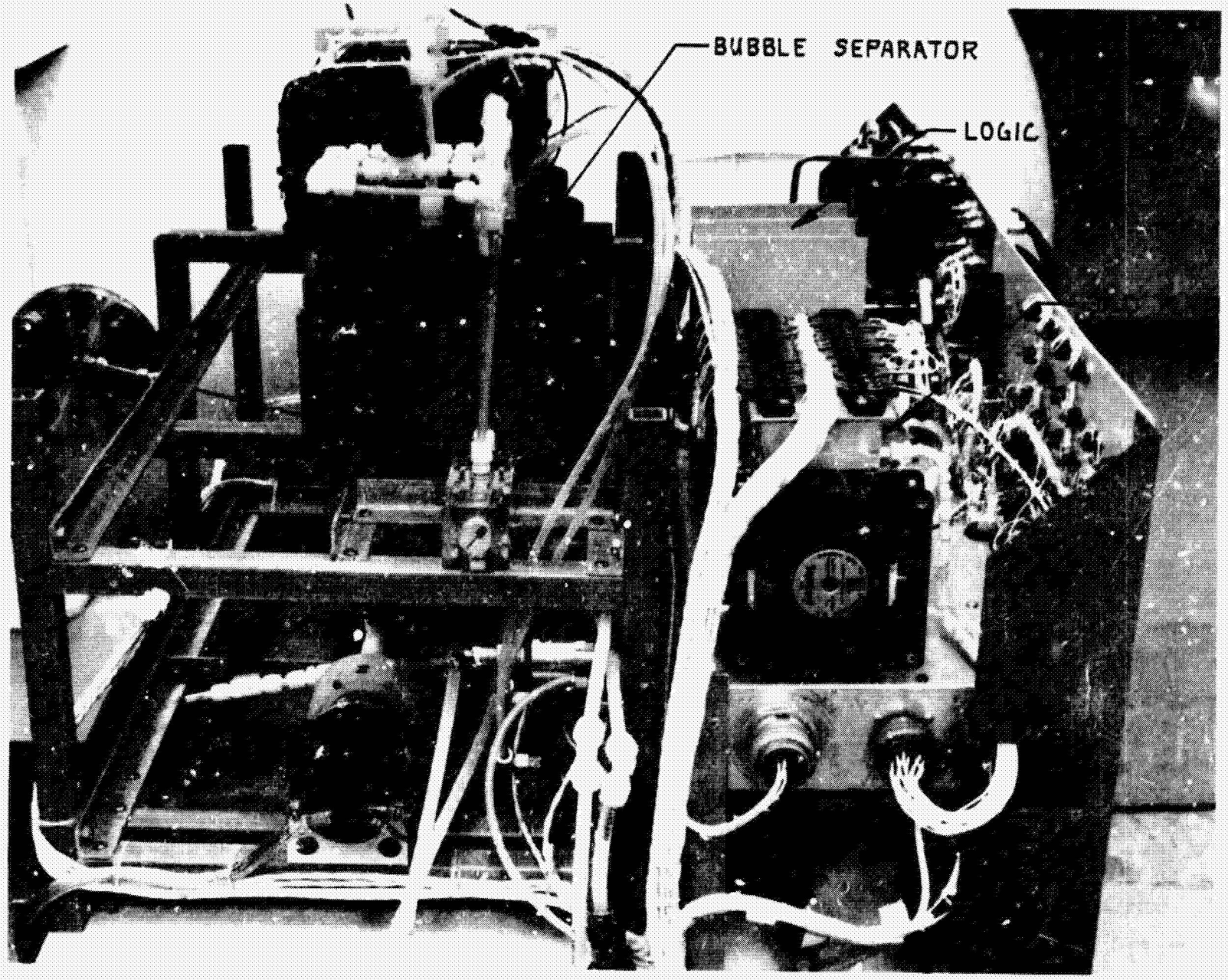


Fig. 2-28 O_2/N_2 System Side View

Table 2-2

SYSTEM CONTROL AND MONITORING INSTRUMENTATION

Parameter	Measurement Technique	Signal Use
Cabin total pressure	Transducer	Current mode control
	Transducer	Strip-chart recorder
	Vacuum gage	Transducer check
Cabin oxygen partial pressure	Polarographic analyzer	Hydrazine feed control
	Polarographic analyzer	Strip-chart recorder
	Paramagnetic analyzer	Polarographic sensor check
Effluent oxygen partial pressure	Polarographic analyzer	Strip-chart recorder and PO_2 safety
Hydrazine feed valve on-off status	Electrical impulse	Strip-chart recorder
Electrolyte temperature	Thermoswitch	Coolant solenoid valve control
Module temperature	Thermoswitch 2-position	Overtemperature warning and shutdown
Coolant temperature	Thermometer	Data logging
Cell bank current	Shunt and digital voltmeter	Data logging
Cell bank voltage	Digital voltmeter	Data logging
Individual cell voltages	Digital voltmeter	Data logging
High/low current mode time	High/low mode timers	Data logging
Metabolic/leak flow rate	Rotameter and wet test meter	Data logging
Nitrogen makeup flow rate	Rotameter	Data logging
Hydrazine flow rate	Rotameter	Data logging
Electrolyte circulation rate	Rotameter	Data logging
Coolant flow rate	Rotameter	Data logging
Hydrogen production	Wet test meter	Data logging
Electrolyte volume	Microswitch – piston position	Water feel control
	Microswitch – piston position	High/low volume safety
Cabin sampling loop pressure	Pressure gage	PO_2 sensor calibration
Module pressure	Pressure gage	Data logging
Hydrazine tank pressure	Pressure gage	Safety check
Bubble separator gas evolution rate	Water volume displacement	Data logging
Input electrolysis power	Power supply voltmeter and ammeter	Data logging

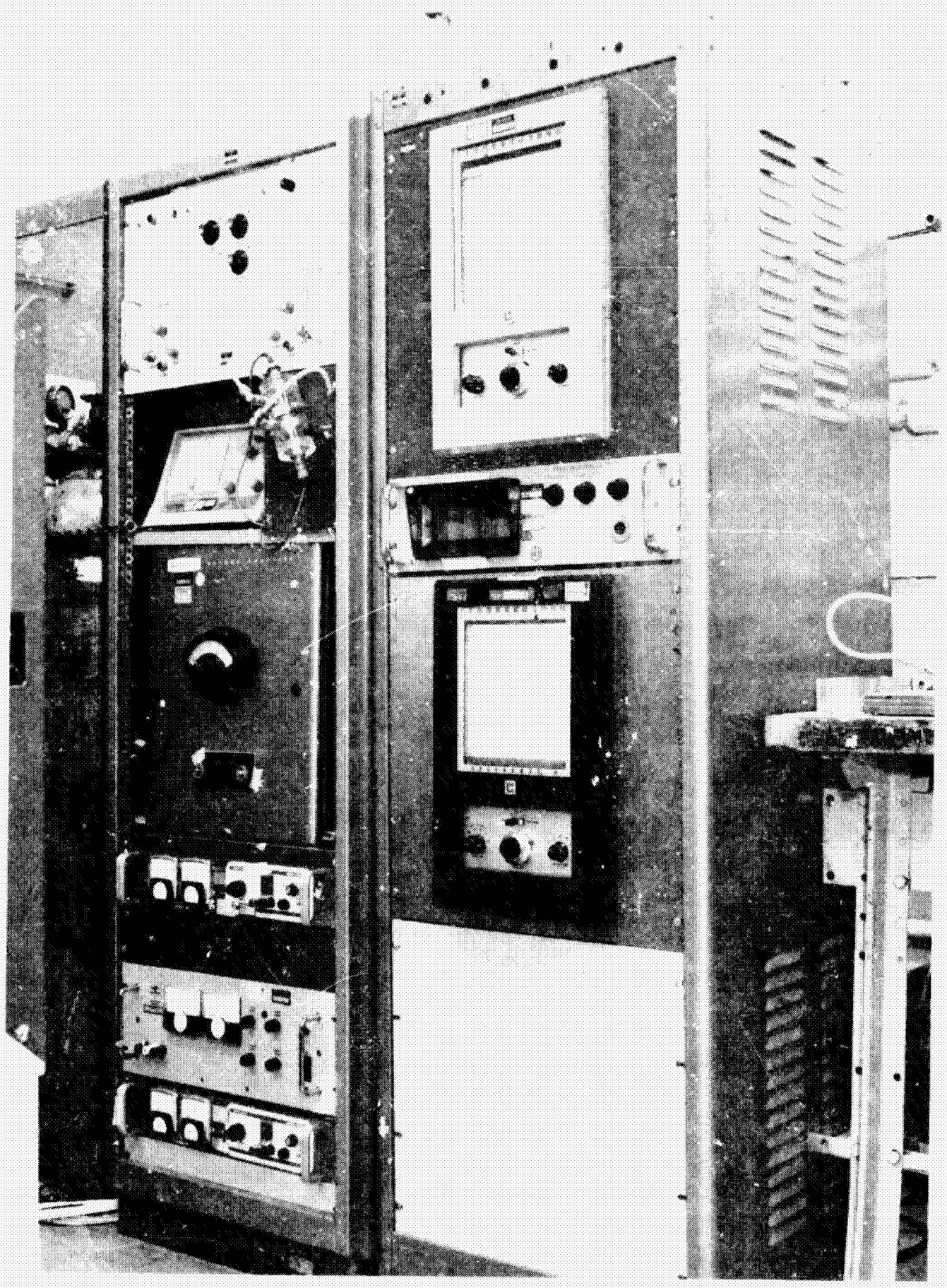


Fig. 2-29 Test Instrumentation

2.3 SYSTEM TESTING

Testing of the one-man model O_2/N_2 system was conducted under this program with the objectives of evaluating the performance of various system components, establishing the characteristics of the cabin atmosphere control that can be achieved with this technique, and providing experimental data for the updating and verification of a computer routine model of the system.

2.3.1 Operating Procedure

The test plan that was established for meeting the objectives stated above involved a series of tests. Each test was conducted in a continuous operating mode with around-the-clock monitoring. The duration of each test was determined by the specific data requirements. Long-duration testing of the basic electrolysis system in previous programs (Ref. 3) has already established the capability of a system of this type to operate continuously for periods exceeding one year.

Startup-Shutdown Procedures. The detailed procedure for starting up and shutting down the system is described in Appendix B. The general approach to startup was to establish control conditions as rapidly as possible so as to allow the major part of a week for operation under automatic control conditions. This required that the cabin simulator be evacuated by increasing the metabolic/leak flow and manually adjusting the N_2 makeup flow to maintain the cabin PO_2 near the control band. At the same time, the hydrazine feed rate had to be increased to enrich the hydrazine concentration in the electrolyte.

Data Logging. While only the hydrazine concentration in the electrolyte, cabin total pressure, and cabin oxygen partial pressure were required data for computer routine analysis, additional module and system status data were recorded on an hourly basis to allow a thorough analysis of the system operating characteristics. The test data logs are included in Appendix C.

Test Monitoring. Around-the-clock monitoring was provided during system testing. The metabolic/leak and nitrogen makeup flow rates, which tended to drift, were adjusted as necessary. The cabin and effluent PO_2 sensors were calibrated every 8 hr in the first test, but little drift was observed. In subsequent tests, these sensors were calibrated at the beginning and end of each test.

The water storage tank was filled with a known volume at the beginning of each test and the residual was measured at the end. Hydrazine consumption was measured by draining and back-filling the hydrazine tank at the end of each cabin PO_2 cycle.

Gas and Electrolyte Sampling. Periodic sampling of the effluent gases was conducted to verify the PO_2 sensor readings. The samples were analyzed using gas chromatographic techniques.

Electrolyte samples were taken just prior to the closing of the hydrazine solenoid valve, to obtain the maximum hydrazine concentration, and just prior to the opening of the feed valve, to obtain the minimum hydrazine concentration. Chemical analysis of the electrolyte samples for hydrazine content utilized the direct iodate method with solvent (Ref. 6).

2.3.2 System Test Summary

A series of four tests was conducted on the one-man model O_2/N_2 system. The test sequence logic is shown in Fig. 2-30.

The objectives of the first test were to check out the operation of the fully integrated O_2/N_2 generation system as well as the cabin and metabolic/leakage simulator, and to establish the test procedure for subsequent tests. Highlights of this test include:

- Successful operation of the zero-gravity closed reservoir and bubble separator.
- Verification of P_{total} control for a fixed metabolic and leak rate at a control band of 12.28 to 12.30 psia.

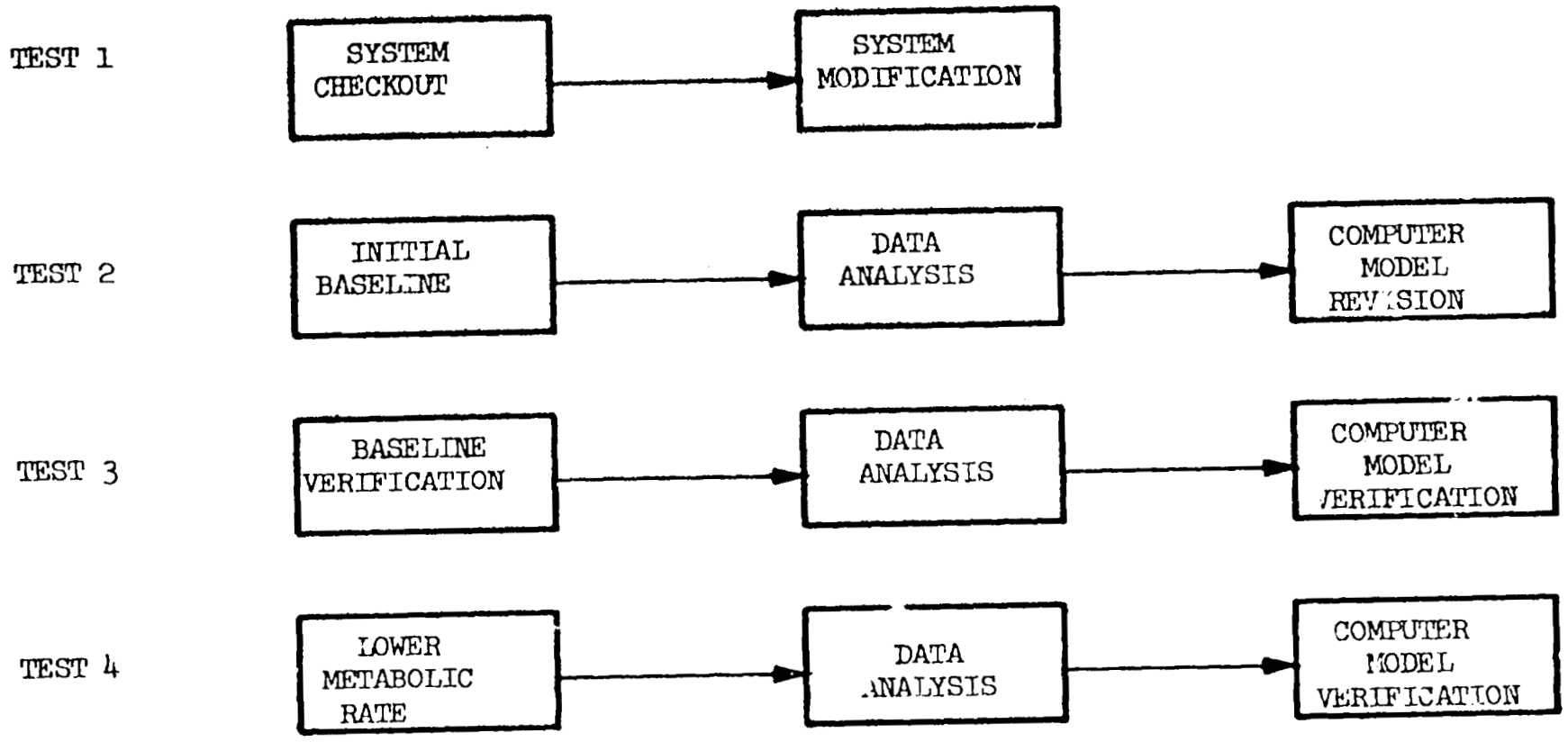


Fig. 2-30 System Test Sequence

- An indication of cabin PO_2 control at a control band of 2.85 to 2.95 psia. A full PO_2 cycle was not completed.
- Nitrogen in the effluent oxygen measured over a range from 0 to 91 percent.

Several system and procedure modifications indicated by this test were implemented before proceeding to the next test. These modifications are discussed in detail in Section 2.3.3.

Test 2 was the initial baseline run of the system at the design conditions; that is, at a one-man metabolic load with a one-man proportion of a space cabin leakage. Summary results of this test showing the cabin total pressure and oxygen partial pressure control are given in Fig. 2-31.

The baseline was rerun in Test 3 to provide data for verification of the computer model revision. The summary results of this test are shown in Fig. 2-32.

In Test 4, both the high/low currents and the metabolic load were varied to provide a different set of data points. In the one-man system, changes in metabolic load were made, approximately corresponding to reducing the crew size from 12 men to 3, 6, and then to 10 men. Summary results are shown in Fig. 2-33.

2.3.3 Test Results and Discussion

2.3.3.1 Test Logs and Performance Data

Test 1 Results. An operational checkout test was conducted for a duration of 86 hr. The Time/Event Log for this test is presented in Table 2-3.

Cabin PO_2 and hydrazine concentration for the period from 46 to 81 hr elapsed time are shown in Fig. 2-34. The shaded area in this figure is the control signal band that was shifted at 54 hr to correct for the higher pressure in the sensor canister. PO_2 control capability was demonstrated by the turnaround of the cabin PO_2 at approximately 61 hr. A full cycle of the PO_2 was not achieved because of a problem with the water feed, which occurred at 81 hr.

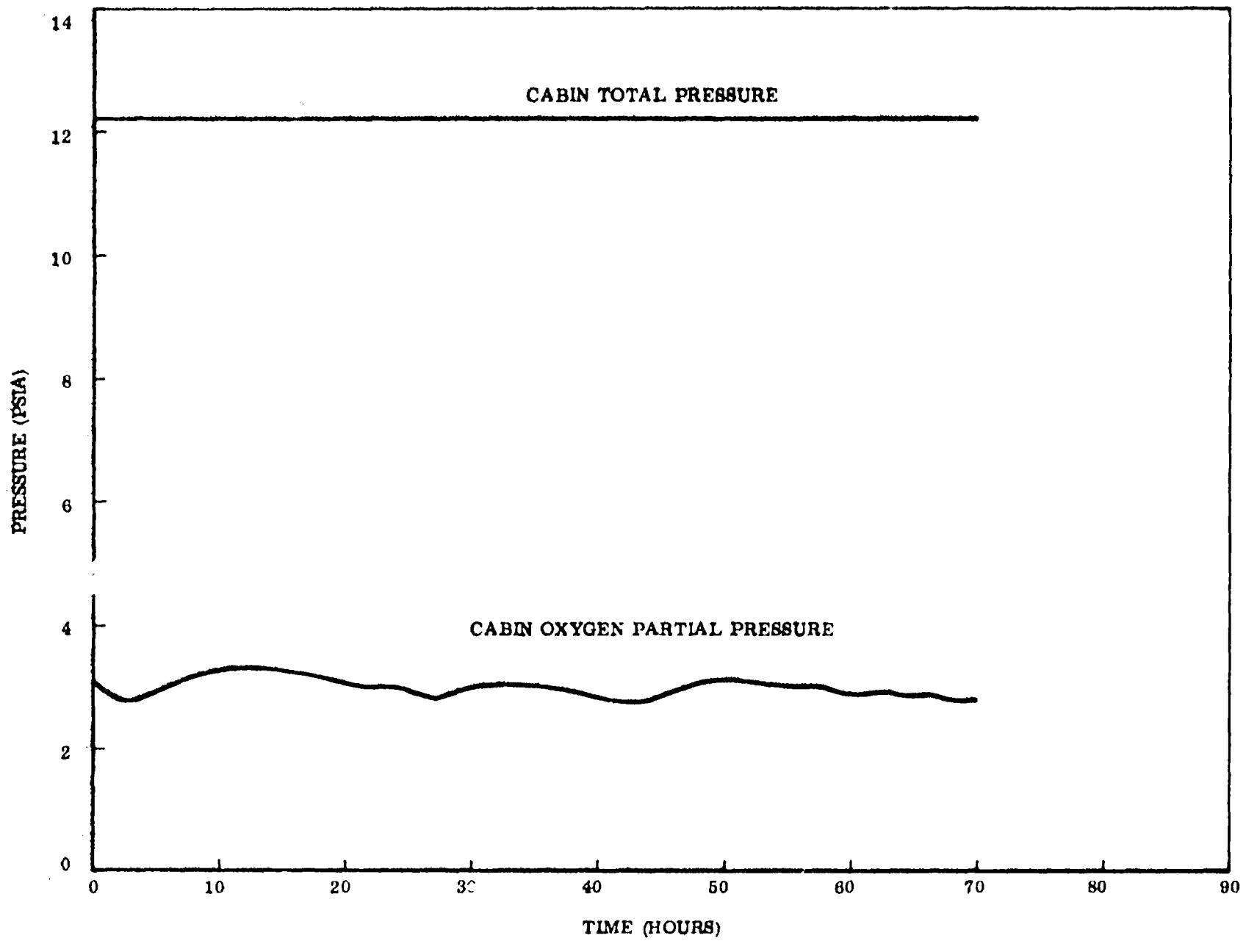


Fig. 2-31 Test 2 – Cabin Atmosphere Control

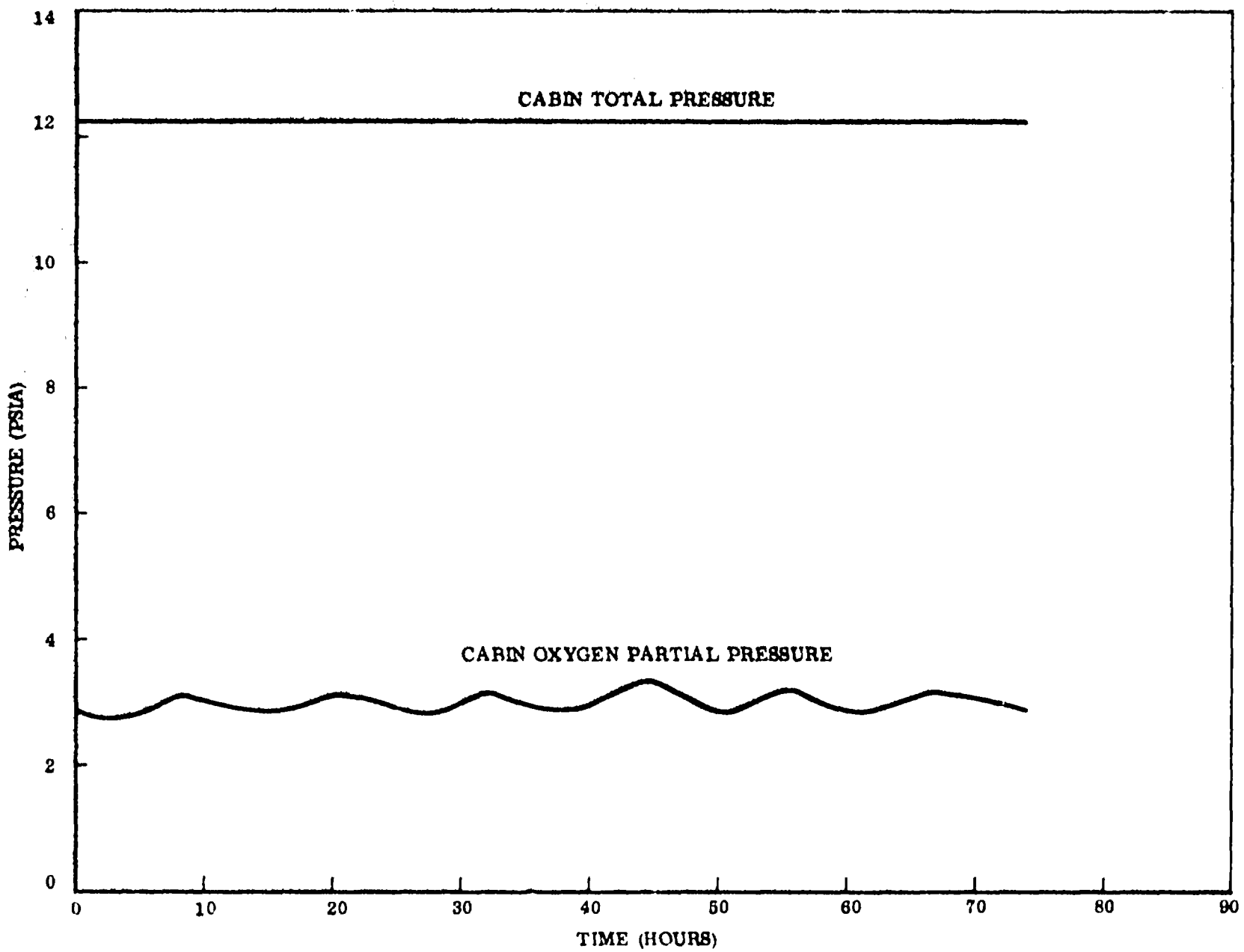


Fig. 2-32 Test 3 – Cabin Atmosphere Control

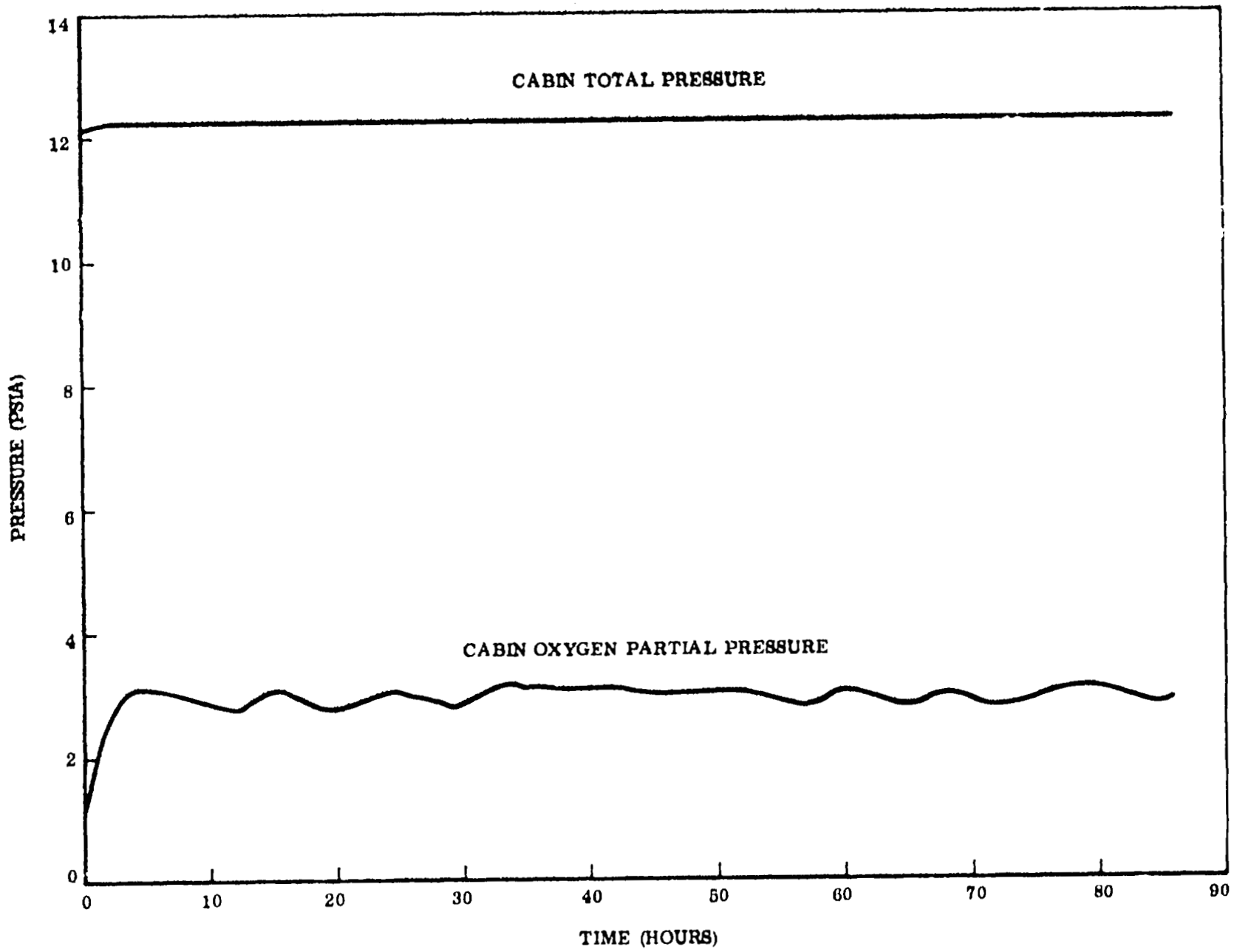


Fig. 2-33 Test 4 – Cabin Atmosphere Control

Table 2-3

TEST 1 – TIME/EVENT LOG

Elapsed Time (hr)	Events/Actions	Criteria
8	Leak in the plumbing between the cell stack and the cabin simulator detected and corrected	High cabin pressure observed
18	$N_2 H_4$ flowmeter replaced	Range of flowmeter incorrect
54	Calibration of PO_2 sensors changed from 174 to 155 mm Hg	Calibration not previously corrected for 2 psig in sensor canister
78.8	Automatic safety shutdown	Water feed failed "on," and high-volume shutdown actuated
81	System returned to manual mode	
86	Test terminated	

At this point the reservoir piston had moved, because of the hydrazine addition, to a point where both the "on" and "off" water feed control microswitches were actuated. An error in the control logic permitted the "on" command to override the "off" command and resulted in continuous feed until the high reservoir volume signal shut down the system.

The system was restarted and operated for another 5 hr in a manual mode.

The following modifications to the system and test procedure were implemented as a result of this test:

- The PO_2 safety shutdown logic was modified to simply shut off the hydrazine feed solenoid valve, rather than shutting down the entire system. That is,

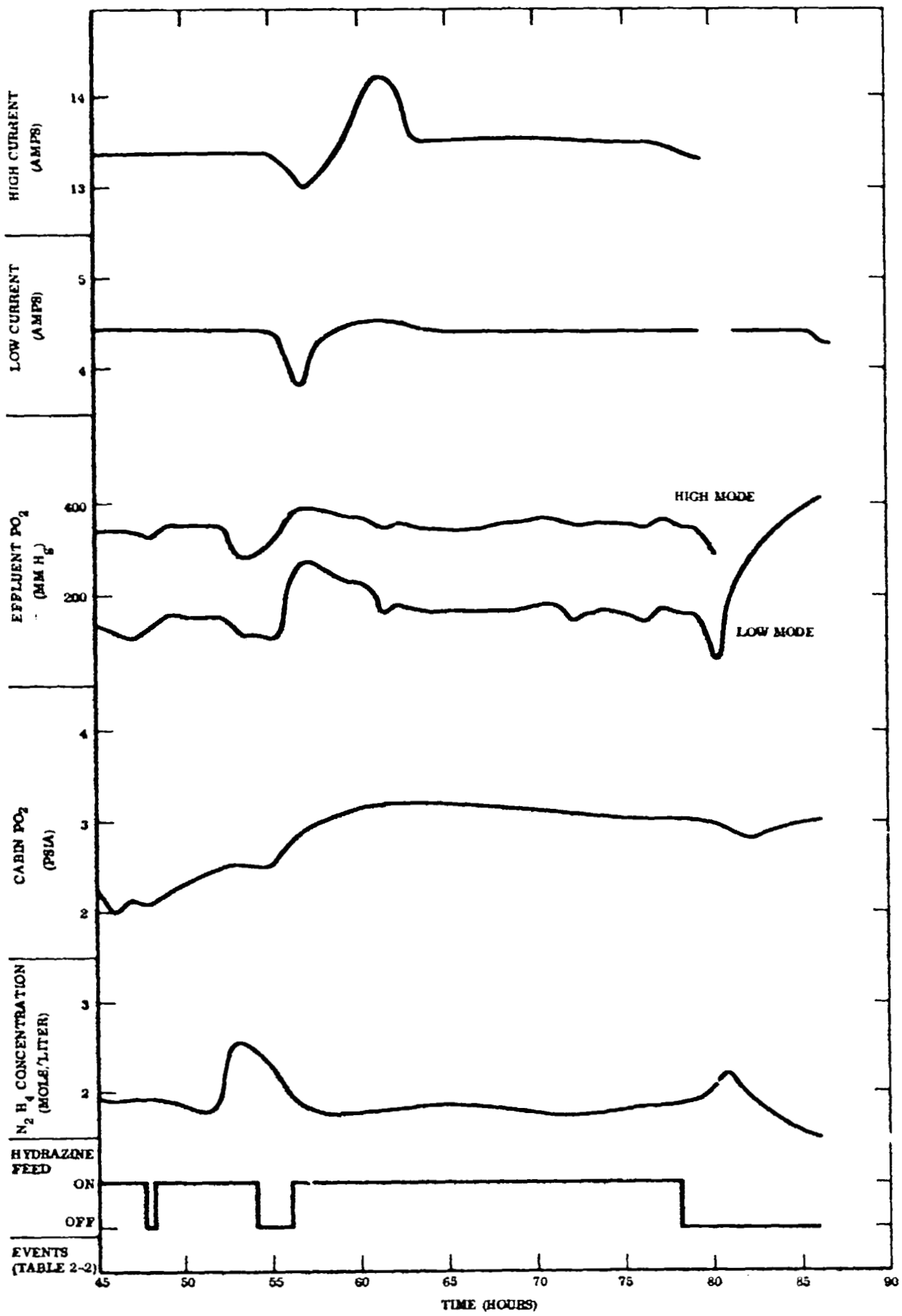


Fig. 2-34 Test 1 – Partial Plot of Performance

when the PO_2 in the unit effluent decreased below 150 mm, the hydrazine feed would be stopped. This change resulted from observing a much faster hydrazine decay rate in the electrolyte than had been anticipated.

- A wet test meter was installed downstream of the metabolic/leak flowmeter to provide a more accurate measure of the gas removed from the cabin.
- The water feed control logic was corrected to assure positive shutoff in the event both "on" and "off" switches were actuated.
- The startup procedure was changed to include an initial hydrazine feed higher than the set point as a test expediency to shorten the test time required to achieve PO_2 control.

Test 2 Results. An initial baseline run was conducted with the objective of determining the P_T and PO_2 control characteristics at design conditions. The metabolic/leak and nitrogen makeup flow rates were set at the design point of a one-man metabolic load (1.84 lb/day) and a cabin leakage of one-twelfth of the spacecraft leakage rate of 13 lb/day at 10 psia. The P_{Total} control signal band was set for 12.23 to 12.25 psia, and the cabin PO_2 control signal band was set for 2.8 to 2.9 psia. The high/low current modes were set approximately at 150/50 mA/cm^2.

A performance plot and the Time/Event Log for the 70 hr of this test are shown in Fig. 2-35 and Table 2-4, respectively.

P_{Total} is not shown on the figure; it remained within the control band for the entire test.

It can be seen in these performance data that the PO_2 control and hydrazine concentration in the electrolyte were erratic; although not out of control.

During the first PO_2 cycle, several upward adjustments of the hydrazine feed rate were made because the PO_2 overshoot of the control band appeared excessive and the cycle time appeared to be too long. At 39 hr, the hydrazine tank ran empty, before the end of the feed cycle, and was recharged. The amount of hydrazine in the original

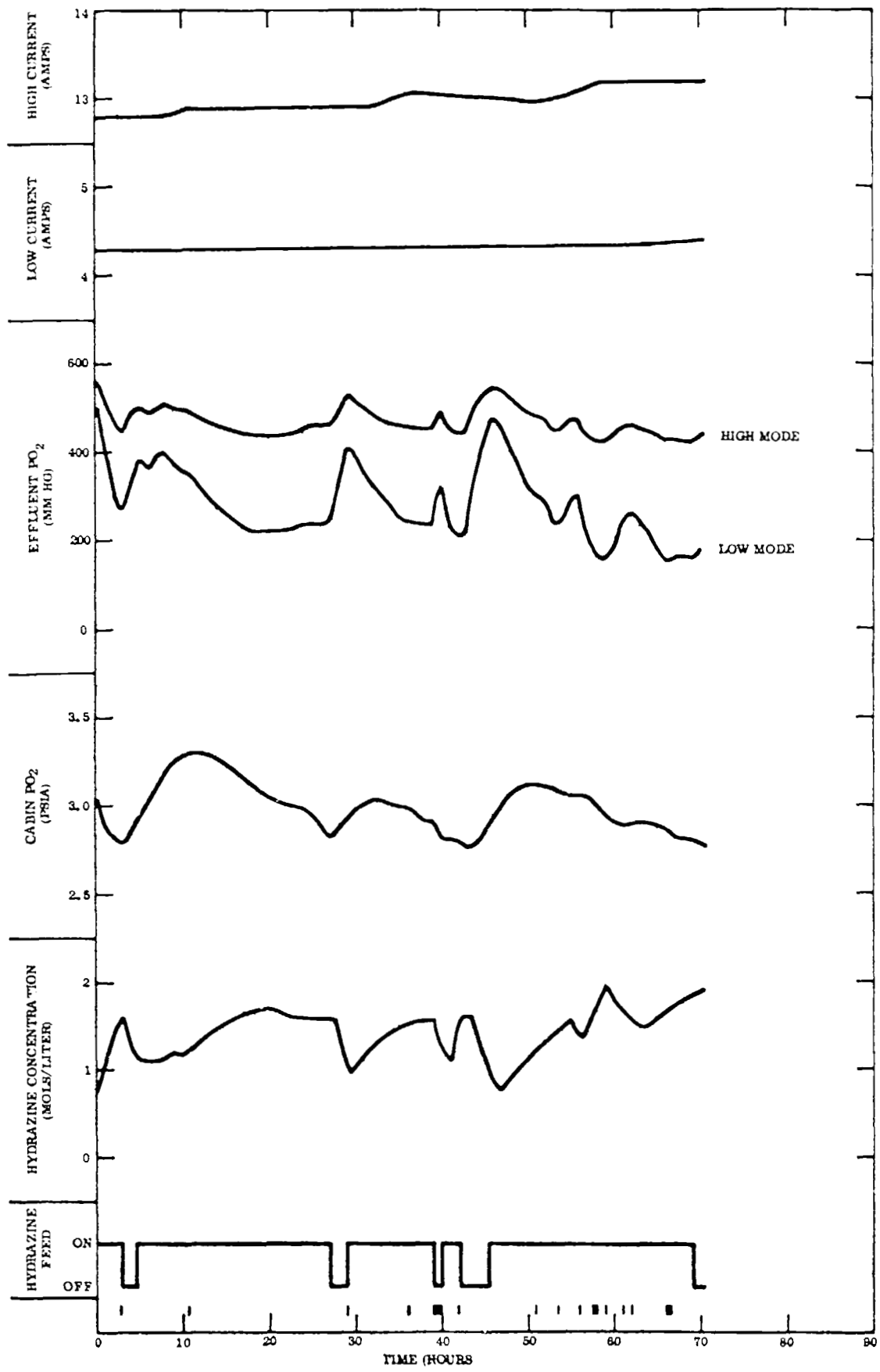


Fig. 2-35 Test 2 – Performance Data

Table 2-4

TEST 2 – TIME/EVENT LOG

Elapsed Time (hr)	Events/Action	Criteria
2.7	Metabolic/leak and N_2 makeup set to correct settings for automatic control run; N_2H_4 at 6.0 flowmeter reading	N_2H_4 feed cycled off automatically
10.5	Adjusted N_2H_4 to 7.0 flowmeter reading	Cabin PO_2 appeared to be overshooting, indicating N_2H_4 feed rate too low
29	Adjusted N_2H_4 to 7.5 flowmeter reading	N_2H_4 feed cycled on and flow rate appeared low
36 to 36.2	N_2 makeup supply cylinder replaced	No-flow indication on flow control panel
39 to 40	Recharged N_2H_4 tank; flow set high to restore hydrazine concentration in electrolyte	Tank ran empty
42	Adjusted N_2H_4 to 5.8 flowmeter reading	Cabin PO_2 appeared to be decreasing too rapidly
51	Decreased coolant supply temperature to 35°F	Coolant to heat exchanger not cycling
53.5	Adjusted N_2H_4 to 5.8 flowmeter reading	
56	Adjusted N_2H_4 to 7.7 flowmeter reading	Cabin PO_2 leveled off
57.5 to 58.0	Repeated adjustment of N_2H_4 downward to 6.5 from 7.6	
59	Adjusted N_2H_4 to 6.0 flowmeter reading	
61	Adjusted N_2H_4 to 6.[illegible] flowmeter reading	
62	Adjusted N_2H_4 to 7.0 flowmeter reading	
66 to 66.5	Adjusted N_2H_4 to 6.9 flowmeter reading, then to 6.5	

charge had been predetermined based on the nitrogen load and was not expected to run out for another 12 hr. This incident shed doubt on the accuracy of the hydrazine flowmeter and led the test conductors to frequently adjust the hydrazine flow control valve setting during the remainder of the test in an effort to find the correct setting.

At the conclusion of the test it was still not clear why, during the first 40 hr of the test, a higher indicated flow rate was required than during the remainder of the test. Analysis of the hydrazine concentration in the solutions used to charge the tank revealed a discrepancy. In the first charge, bottles of hydrazine fresh from the manufacturer and labeled 95 percent were diluted with water by an amount which would make the desired solution 64 percent. Several bottles of this "95 percent" solution were analyzed and found to contain 64 percent solution. Because of the mislabeling, the actual solution had been diluted for charging the tank to approximately 40 percent. Further checking showed that the second charge of the tank was made with 64 percent solution.

Two problems with the hydrazine flow control were identified during the test, only one of which had an easy solution. First, the micrometer valve was too coarse and was replaced with a finer needle valve after the test was completed. Second, the valve body was made of 316 stainless steel, which was not completely compatible with hydrazine. A very slight decomposition of hydrazine inside the valve caused small gas bubbles to form in the flow steam. These small bubbles collected on the ball floats in the rotameter and gave rise to erroneous flow rate readings. The procedure for the next test was modified to include draining and recharging the hydrazine tank at the end of each feed cycle. By measuring the volume of the charge and the residual for each cycle, the consumption of hydrazine and the average feed rate for each cycle could then be determined.

Test 3 Results. The baseline operating conditions used in Test 2 were utilized in this test with the objective of obtaining a sufficient number of repeatable PO_2 cycles to provide data for verifying the computer model revision. The only condition that was modified was the PO_2 control signal band. It was changed from 2.8 – 2.9 psia to 2.85 – 3.00 psia as a result of recalibration of the sensors and the control electronics.

The performance data for Test 3 are shown in Fig. 2-36 and the Time/Events Log in Table 2-5.

During the first PO_2 cycle, several operator adjustments of the hydrazine flow control valve were made in seeking the proper flow setting. After the first cycle, no further adjustments of the flow setting were made for the duration of the test.

The only problems that occurred during the test were two occasions when the hydrazine solenoid valve did not open on command. The first time this happened (at 6 hr elapsed time), the test conductor observed it immediately and was able to manually pulse the valve open. On the second occasion, however, the command and failure to open occurred at 41 hr and was not noticed until 42.7 hr. This resulted in the higher PO_2 overshoot shown in Fig. 2-36 for the fourth cycle. With this exception, adequate PO_2 control was demonstrated and reasonably repeatable cycles were obtained.

For the next test, the procedure for measuring hydrazine consumption was changed from a volume measurement to a weight measurement. This was done to increase the accuracy of the measurement and to reduce the handling required.

Test 4 Results. This test was run for a period of 86 hr with the objective of providing performance data at conditions different from the baseline. The performance data and Time/Event Log for this test are shown in Fig. 2-37 and Table 2-6, respectively.

During the first 29 hr of the test the baseline conditions were used, the only difference being that the low current was set at approximately 75 mA/cm^2 rather than the baseline value of 50 mA/cm^2.

At 29 hr, the metabolic/leak and nitrogen makeup flow rates were changed corresponding to a change in a 12-man cabin from a 12-man to a 3-man metabolic load with no change in the cabin leakage.

After 45 minutes of operation under these conditions it was observed that cabin pressure, P_T was steadily increasing with the current in the low mode. This indicated

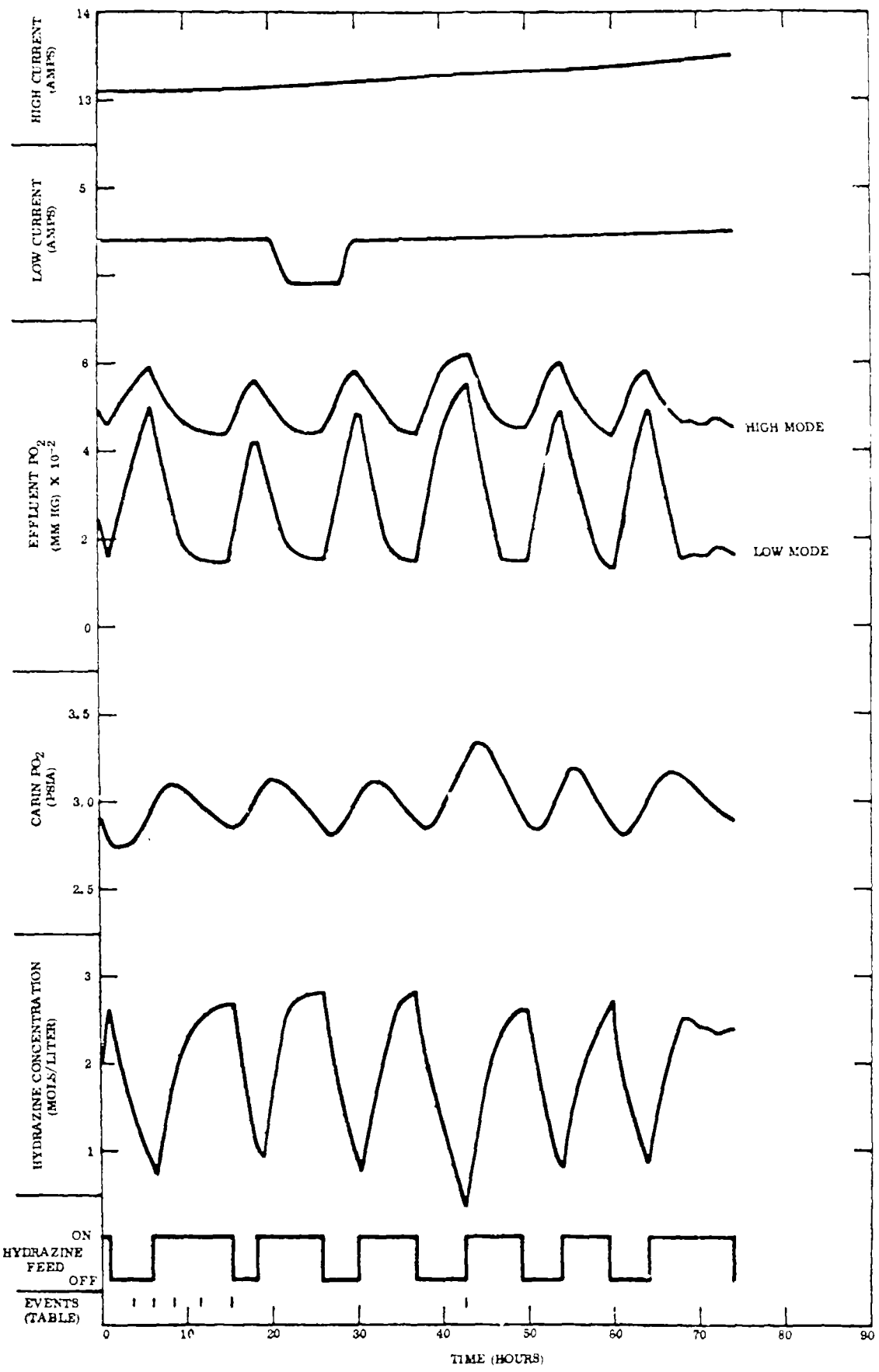


Fig. 2-36 Test 3 – Performance Data

Table 2-5

TEST 3 – TIME/EVENT LOG

Elapsed Time (hr)	Events/Action	Criteria
1.1	Recharged N_2H_4 tank; consumption on first cycle = 425 cc	Procedure
4.75	Adjusted metabolic/leak flowrate to 2,190 cc/min	Metabolic leak wet test meter reading low, at 2,110 cc/min
6	N_2H_4 solenoid stuck closed; manually pulsed to open	N_2H_4 feed signal on; no flow observed
8.5	Decreased N_2H_4 flowmeter reading from 8.8 to 7.7	Noted electrolyte pressure increasing at approximately 1 in. H_2O/hr
10	Increased N_2H_4 flowmeter reading to 8.8	Noted electrolyte pressure dropping rapidly and effluent PO_2 climbing
11.5	Decreased N_2H_4 flowmeter reading to 8.0	Effluent PO_2 safety signal
15.2	Decreased N_2H_4 flowmeter reading to 7.9	Effluent PO_2 safety signal
15.5	Recharged N_2H_4 tank; consumption on second cycle = 580 cc	Procedure
26	Recharged N_2H_4 tank; consumption on third cycle = 510 cc	Procedure
37.3	Recharged N_2H_4 tank; consumption on fourth cycle = 410 cc	Procedure
42.7	N_2H_4 solenoid stuck closed; manually pulsed to open	Noted feed signal on; no flow indicated
50.5	Recharged N_2H_4 tank; consumption on fifth cycle = 425 cc	Procedure
60.3	Recharged N_2H_4 tank; consumption on sixth cycle = 370 cc	Procedure
End of test	Measured N_2H_4 consumption on seventh cycle = 585 cc	Procedure
	Measured H_2O consumption for duration of test = 2,330 cc	Procedure

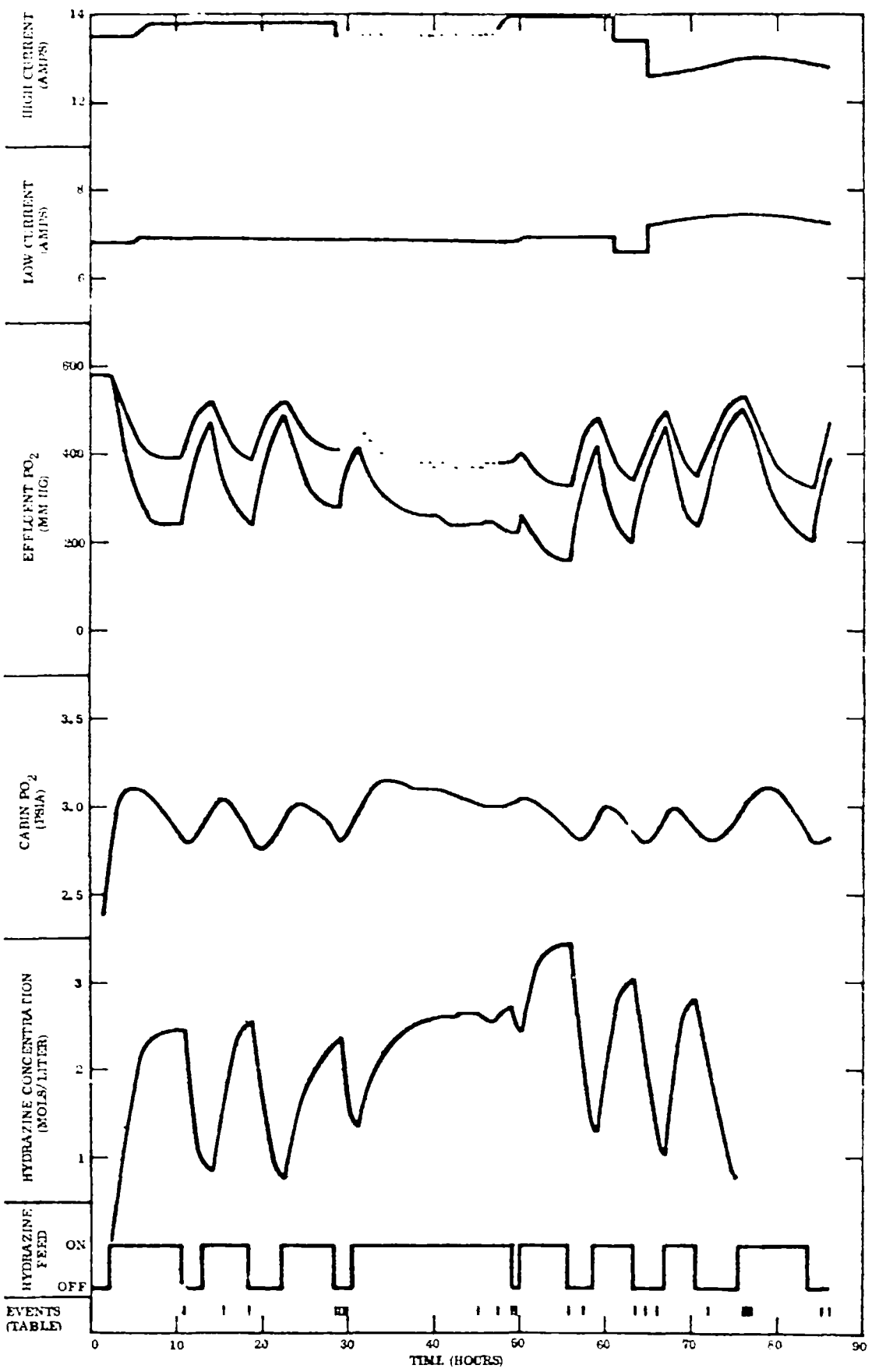


Fig. 2-37 Test 4 – Performance Data

Table 2-6

TEST 4 – TIME/EVENT LOG

Elapsed Time (hr)	Events/Actions	Remarks
11	Recharged N_2H_4 tank; consumption on first cycle = 575 gm	Procedure for measuring N_2H_4 average feed rate
15.5	Adjusted N_2H_4 feed rate to 3.93 valve setting	
18.5	Recharged N_2H_4 tank; consumption on second cycle = 351 gm	Procedure
28.5	Adjusted high current down to 13.5 A	Current reading too high
29	Changed meta/leak and N_2 makeup from 12-man to 3-man metabolic rate	Test condition change
29.5	Recharged N_2H_4 tank; consumption on third cycle = 441 gm	Procedure
29.75	Changed meta/leak and N_2 makeup to 4-man rate	Test condition change[(a)]
45.2	Changed to 5-man rate	Test condition change[(a)]
47.5	Changed to 6-man rate	Test condition change[(a)]
49	Recharged N_2H_4 tank; consumption on fourth cycle = 1,299 gm	Procedure
49.5	Changed to 10-man rate	Test condition change
55.7	Changed to 12-man rate	Test condition change
57.5	Recharged N_2H_4 tank; consumption on fifth cycle = 422 gm	Procedure
63.5	Adjusted high current to 13.5 A	Current too high
64.7	Changed currents: low mode 7.6 A; high mode 12.8 A	Test condition change
66	Recharged N_2H_4 tank; consumption on sixth cycle = 320 gm	Procedure
72	Recharged N_2H_4 tank; consumption on seventh cycle = 289 gm	Procedure
76 to 77	Shut off H_2O and N_2H_4 feed and inserted toggle valve in H_2O feedline. Return both to auto feed mode	Indication by increasing system pressure that H_2O solenoid leaking
85.2	Recharged N_2H_4 tank; consumption on last cycle = 513 gm	Procedure
End of test	Measured H_2O consumption for duration of test = 1,870 cc	Procedure

(a) System pressure rising

that the net flow of gas out of the cabin was less than the net gas flow in from the electrolysis module, and therefore, that P_T control could not be achieved under these conditions. Since an error of only 1 percent in the setting of the metabolic/leak flow rate could cause this problem, it was decided not to continue operation so close to this lower limit of P_T control.

At 29.75 hr, the metabolic/leak and nitrogen makeup were changed corresponding approximately to a four-man metabolic rate. This change restored P_T control and current-mode cycling was observed, although most of the time was being spent in low mode.

From 33 to 48 hr, a steady increase in electrolyte pressure was observed. During this period, electrolyte was manually removed from the system in 10-cc amounts approximately every half-hour to prevent the reservoir from reaching the high-volume shutdown position. Cause of the volume increase was first attributed to the increase in hydrazine concentration and decrease in water consumption resulting from the reduced metabolic load. Step-changes in the metabolic load were continued, going to a five-man rate at 45.2 hr, a six- man rate at 47.5 hr, a 10-man rate at 50 hr, and back to the baseline 12-man rate at 55.7 hr.

After the six-man rate was reached, the problem of increasing electrolyte volume appeared to have been solved.

At 64.7 hr, the high/low currents were changed as shown in Fig. 2-37.

A slow leak through the water feed solenoid valve was detected at 76 hr. A toggle valve was inserted and was operated manually for the remainder of the test. When the solenoid valve was disassembled at the end of the test, it was found that a piece of Teflon plumber's tape used to wrap the pipe threads on the fittings connecting to the valve had settled across the valve seat. This prevented complete closure of the valve and explains the increasing electrolyte volume that was observed during the run at the four- and five-man metabolic rates.

2.3.3.2 Data Analyses

Control Characteristics. The equation describing the variation of cabin total pressure with time can be expressed as (Ref. 7)

$$\frac{dP_T}{dt} = \frac{1}{\lambda T} \frac{dM_T}{dt} \tag{2.3}$$

where

$$\lambda T = \frac{V_C (MW)_T}{RT}$$

$$\frac{dM_T}{dt} = \dot{m}_{T_{in}} - \dot{m}_{T_{out}}$$

In these equations, $\dot{m}_{T_{out}}$ represents the net mass outflow rate from the cabin, i.e., metabolic consumption plus cabin leakage. The total gas, oxygen plus nitrogen, supplied to the cabin by the O_2/N_2 generator is represented by $\dot{m}_{T_{in}}$ and is related to the number of cells, n, and the applied current, Y, by

$$\dot{m}_{T_{in}} = \gamma n Y \tag{2.4}$$

where γ is a constant.

Because the gas input rate is directly proportional to the current, two-position, high/low current control of P_T will have a cyclic characteristic and $\frac{dP_T}{dt}$ will be linear.

An expression for the cabin oxygen partial pressure variation with time, similar to that for P_T, can be written as

$$\frac{dPO_2}{dt} = \frac{1}{\lambda O_2} \frac{dMO_2}{dt} \tag{2.5}$$

where

$$\lambda O_2 = \frac{V_C (MW)_{O_2}}{RT}$$

$$\frac{dM_{O_2}}{dt} = \dot{m}_{O_2\ in} - \dot{m}_{O_2\ out}$$

the net oxygen input rate, $\dot{m}_{O_2\ in}$, can be expressed in terms of O_2/N_2 system parameters as

$$\dot{m}_{O_2\ in} = \gamma n Y - \alpha n C - \beta n C Y$$

where

α and β = constants

C = hydrazine concentration in electrolyte

The hydrazine concentration in the electrolyte at a point in time (t) can be expressed as

$$C = \frac{X}{m} + \left(C_o - \frac{X}{m}\right) \exp \frac{(-mnt)}{V} \qquad (2.6)$$

where

X = hydrazine feed rate

m = reaction rate constant = f(Y)

C_o = hydrazine concentration at $t = t_o$

V = electrolyte volume

It is readily apparent that the control of cabin PO_2 achieved by controlling the hydrazine feed rate, X, is not independent of the current which is used to control P_T.

To illustrate the characteristics of the control of P_T and PO_2 and their interaction, a portion of the analog data from Test 3 was plotted on an expanded time scale and is shown in Fig. 2-38. First, it can be seen that the P_T control is cyclic, with a linear rate of change as predicted by the mathematical description.

Two characteristics of the PO_2 control are evident in this figure. The effect of the exponential time function in the mathematical expression for rate of change of PO_2 is apparent. Furthermore, it can be seen that the P_T cycles are superimposed on the PO_2 curve.

The effluent PO_2 curve on the far left of this figure, which is the oxygen partial pressure in the O_2/N_2 mixture being generated in the cell stack, shows the effects of both the high/low current and the hydrazine feed. The rapid cycling of the effluent PO_2 is the result of the high/low current cycling. The broad cycle of the envelope is the result of the hydrazine concentration in the electrolyte increasing when the hydrazine feed is on, and decaying when the feed is off.

Hydrazine Reaction Efficiency. Data from Test 3 were used to determine the hydrazine reaction efficiency, which is defined as the mol percent of the hydrazine reacting at the anode. The following is a summary of the methods of determination and the results:

a. Nitrogen in the anodic effluent (determined by effluent PO_2 sensor) was compared to the hydrazine feed (determined by measuring volume of N_2H_4 consumed per cycle of the cabin PO_2). This method yielded a hydrazine reaction efficiency of 63 percent.
b. Nitrogen in the anodic effluent (above method) was compared to nitrogen in the cathodic effluent (determined by gas chromatographic analysis). This method yielded a hydrazine reaction efficiency of 59 percent.

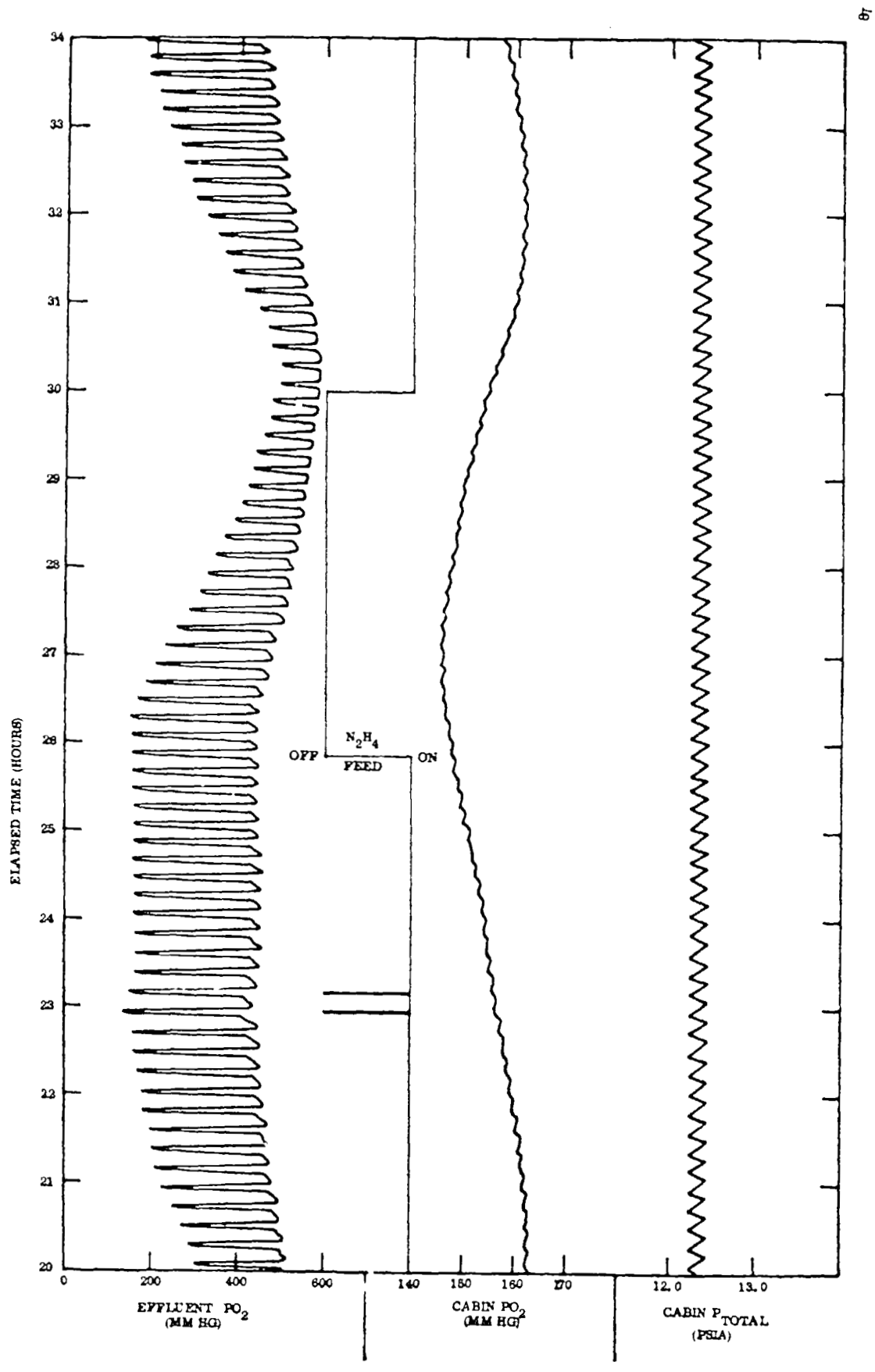


Fig. 2-38 Sample Data From Test 3

c. Nitrogen in the cathodic effluent (determined by the increased cathodic flow-rate) was compared to the hydrazine feed determined in a. This method yielded a value of 62 percent.

Method b. involved point measurements whereas methods a. and c. utilized values averaged over a several-hour period. Details of the computations, data, and data references are given in Tables 2-7, 2-8, and 2-9. The results shown in these tables were averaged to obtain the efficiences given above.

It should be noted that the inefficiency of the hydrazine reaction, which amounts to that hydrazine reacting undesirably at the cathode, is a function of the catalytic activity of the cathode. Single-cell tests have demonstrated that by sufficiently reducing the catalytic activity of the cathode, cathodic hydrazine reaction can be essentially eliminated. However, an increase in electrode polarization also occurs. Data from these tests are shown in Tables 2-10 and 2-11. In Table 2-10, the data were taken at a current density of 50 mA/cm^2, and in Table 2-11 at 75 mA/cm^2. Two separate cells were run, one containing the standard commercial (black platinum/Teflon) cathode and the second in which bare expanded nickel screen was used as the cathode with no platinum catalyst. From these limited data, it is apparent that the low catalytic activity cathode does not induce hydrazine decomposition. Note the lower cathodic flow rate for the low-activity cathode and the absence of N_2 in the chromatographically analyzed cathodic gas samples.

Reaction Rate Constant. The hydrazine reaction rate constant is defined as

$$m = \frac{1}{C} \frac{dC}{dt}$$

and is truly a constant for a fixed cell geometry, temperature, and current. The effect of current at constant temperature on the value of m was determined using Test 3 data and is shown graphically in Fig. 2-39. Reducing the cathode catalytic activity to improve the hydrazine reaction efficiency would affect the value of the reaction rate constant.

Table 2-7

HYDRAZINE CONVERSION EFFICIENCY – METHOD 1

Cycle	N_2H_4 Feed (cc)	N_2 in Feed (mol)	Cycle Time	Δt (hr)	N_2 in Anodic Effluent		Mode Time		Total Mode Current		N_2 in Anode Effluent (mol)	Efficiency (%)
					High (%)	Low (%)	High (hr)	Low (hr)	High (A)	Low (A)		
	(a)	(b)	(c)	(d)	(e)		(f)		(g)		(h)	(i)
1	580	11.6	6.17 to 18.1	11.93	27.4	63.4	8.04	3.89	224.5	75.64	6.56	56.5
2	510	10.2	18.1 to 30.1	12.0	32.0	59.7	7.57	4.43	225.8	71.53	7.06	69.1
3	410	8.2	30.1 to 42.75	12.65	24.7	52.3	8.04	4.61	226.2	75.78	6.08	74.3
4	425	8.5	42.75 to 53.4	10.65	24.5	63.2	6.26	4.39	227.9	74.30	5.34	62.8
5	370	7.4	53.4 to 63.95	10.55	23.5	55.6	6.64	3.91	226.2	74.28	4.93	66.7
6	585	11.7	63.95 to 73.94	9.99	28.1	65.7	6.97	3.02	228.4	74.94	5.73	49.1

(a) Volume of hydrazine consumed – Determined by measuring volume of initial charge and residual in hydrazine tank for each PO_2 cycle.

(b) Amount of nitrogen contained in Col. (a) – 64 percent $N_2H_4 \approx 20$ mole/liter ≈ 0.002 mole/cc; 1 mol N_2H_4 contains one mole of cc; N_2 in feed = Col. a $\times$ 0.002.

(c) Cycle time – Times correspond to N_2H_4 feed cycles (see Fig. 2-36).

(d) Δt – time interval between N_2H_4 feed initiations.

(e) Percentage of N_2 in anodic effluent – Average N_2 concentration, determined by measuring the area under the PO_2 effluent curve (Fig. 2-36) for the high and low current modes for time periods (c), dividing by Col. (d) to obtain PO_2 avg, and computing the value of $\%N_{2_{avg}} = [(P_T - PO_{2_{avg}})/P_T] \times 100$ where $P_T \simeq 12.23$.

(f) High and low mode time – Determined by measuring total time on P_T strip-chart recorder during which P_T was increasing (equivalent to high current mode time) and the total time that P_T was decreasing (equivalent to low current mode time).

(g) Total current, high and low mode – Total current in each mode, that is, average current during a cycle multiplied by the number of cells; determined by measuring the area under the current curve (Fig 2-36) with a planimeter, dividing the area by (d) to obtain average current, and multiplying by 17, the number of cells.

(h) Number of mol of N_2 in anodic effluent during the cycle – determined by computing the value of mol N_2 = 0.0096 [(Col. e)$_H$ (Col. f)$_H$ (Col. g)$_H$ + (Col. e)$_L$ (Col. f)$_L$ (Col. g)$_L$] where 0.0096 is the constant k converted from SCC/min to mol/hr.

(i) Hydrazine conversion efficiency – Determined by computing the value η(efficiency) = (Col. h/Col. b) $\times$ 100 .

Table 2-8

HYDRAZINE CONVERSION EFFICIENCY – METHOD 2

Elapsed Time (hr)	I (A)	Percent N_2 (H_2)	N_2 in H_2 (mol/hr)	Eff PO_2 (mm)	N_2 in O_2 (%)	N_2 in O_2 (mol/hr)	Efficiency (%)
	(a)	(b)	(c)	(d)	(e)	(f)	(g)
-0.2	12.9	6.8	0.359	510	22.1	0.465	56.5
1.27	4.3	13.3	0.310	160	75.8	0.533	63.3
1.38	13.1	7.3	0.399	480	26.7	0.572	58.9
7.0	13.1	4.3	0.210	570	13.0	0.279	57.0
16.13	13.3	7.9	0.449	500	23.6	0.512	53.3
30.25	13.2	3.1	0.148	600	8.4	0.181	55.1
37.33	13.4	8.7	0.514	450	31.2	0.683	57.1
59.73	13.4	7.4	0.415	430	34.3	0.751	64.5
60.0	4.5	14.4	0.372	130	80.2	0.590	61.3
65.7	13.4	5.4	0.282	530	19.0	0.416	59.6
65.95	4.4	12.9	0.302	290	55.7	0.400	57.1

(a) Current – Average cell current for the two cell stacks.

(b) Percentage of N_2 in cathodic effluent – gas chromatographic analysis.

(c) Nitrogen generation rate at cathode – determined by the following computation:

$$(H_2)_e = 2 \times 17 \times 0.0096 \times \text{Col. a}$$

$$\dot{m}_{TC} = (H_2)_e \times X_1 \times X_2 ,$$

where $(H_2)_e$ = H_2 generated electrochemically (mol/hr)

$\dot{m}_{TC}$ = total gas generated at cathode (mol/hr)

X_1 = mol/hr N_2 from N_2H_4

X_2 = mol/hr H_2 from $N_2H_4 = 2X_1$

X_1 = Col. b $\times \dot{m}_{TC}$ = Col. b $\times H_2 \times$ Col. c + $3X_1$

X_1 = [Col. b $\times (H_2)_e$] $\div$ [1 - (3 $\times$ Col. b)]

(d) Effluent PO_2 – Instantaneous value of effluent PO_2 at the time the gas chromatograph sample was taken (see Fig. 2-28).

(e) Percentage of N_2 in anodic effluent – Determined by computing $\%N_2 = (P_T - \text{Col. d})/P_T$.

(f) Nitrogen generation rate at anode – Determined by computing $\dot{m}_{N_2} = 17(0.0096) \times$ Col. a $\times$ Col. e.

(g) Hydrazine conversion efficiency – Determined by computing η = Col. f/(Col. c + Col. f $\times$ 100)

Table 2-9

HYDRAZINE CONVERSION EFFICIENCY – METHOD 3

Cycle	Cathodic Gas Flow (cc)	Cathodic Gas Flow (mol)	$(H_2)_e$ (mols)	Efficiency (%)
	(a)	(b)	(c)	(d)
1	1,130	46.5	40.4	82.5
2	1,320	54.3	38 9	50.0
3	1,100	45.2	41.7	83.4
4	1,120	46.1	33.7	49.0
5	1,090	44.8	34.4	53.2
6	1,040	42.7	34.9	77.8

(a) Cathodic gas flow (cc) – Total cathodic gas per cycle measured with wet test meter (See Appendix C)

(b) Cathodic gas flow (mol) – Total cathodic gas per cycle converted from cubic centimeters to mols.

(c) Electrochemically generated H_2 – Determined from data in Table 2-8 by computing

$$\left(H_2\right)_e = 2\,(0.0096)\left(I_{T_h}\, t_h + I_{T_\ell}\, t_\ell\right)$$

(d) Hydrazine conversion efficiency – Determined by computing

$$\dot{m}_{T_C} = \left(H_2\right)_e + \left(X_1\right)_{N_2} + 2\left(X_1\right)_{H_2}$$

$$X_1 = \dot{m}_{T_C} - (H_2)_e$$

$$\eta = \frac{N_2H_4 \text{ feed (mol)} - X_1}{N_2H_4 \text{ feed (mol)}} \times 100$$

Table 2-10

HYDRAZINE CONVERSION – TEST 1

Standard Cell							Cell With Reduced Cathode Activity						
Time	Flow (cc/min)		Nitrogen Content (%)		N_2H_4 Concen. (mol/liter)	Cell Voltage (V)	Time	Flow (cc/min)		Nitrogen Content (%)		N_2H_4 Concen. (mol/liter)	Cell Voltage (V)
	O_2	H_2	O_2	H_2				O_2	H_2	O_2	H_2		
1:33					1.42	1.666	1:33					1.70	2.156
1:40	17.4						2:02		35.8				
1:57		46.2					2:07	17.9					
2:30					1.37								
2:38			43.2				2:33					1.68	
2:57	16.9	46.6					2:45			53.7			
2:53			42.4				3:02			50.3			
3:11				9.6			3:15	17.8	35.5				
3:29				9.6			3:19				0		
3:30						1.668	3:30				0		2.192
4:12			27.6				4:03			46.4			
4:18				8.8			4:28				0		
4:20	17.2	46.3					4:30	17.9	35.3				
Decomposition Rate (No Current) O_2 Side – 10.9 cc/min H_2 Side – 16.7 cc/min							Decomposition Rate (No Current) O_2 Side – 12.6 cc/min H_2 Side – None						

Table 2-11

HYDRAZINE CONVERSION – TEST 2

Standard Cell							Cell With Reduced Cathode Activity						
Time	Flow (cc/min)		Nitrogen Content (%)		N_2H_4 Concen. (mol/liter)	Cell Voltage (V)	Time	Flow (cc/min)		Nitrogen Content (%)		N_2H_4 Concen. (mol/liter)	Cell Voltage (V)
	O_2	H_2	O_2	H_2				O_2	H_2	O_2	H_2		
11:14						1.807	11:18						2.324
11:15		70.0					11:31	26.3	51.6				
11:26	26.3						11:45					1.99	
11:36			37.6				12:11			37.9			
11:45					1.97		12:23			38.9			
11:48			37.9				12:47				0		
12:00			38.2				1:09					1.97	
1:07					1.80		1:50	26.5	53.1	37.3			
1:40			36.5				2:16				0		
1:45	26.2	67.6					2:35			37.3			
1:58				7.8									
2:04				7.6									
2:25			36.2										

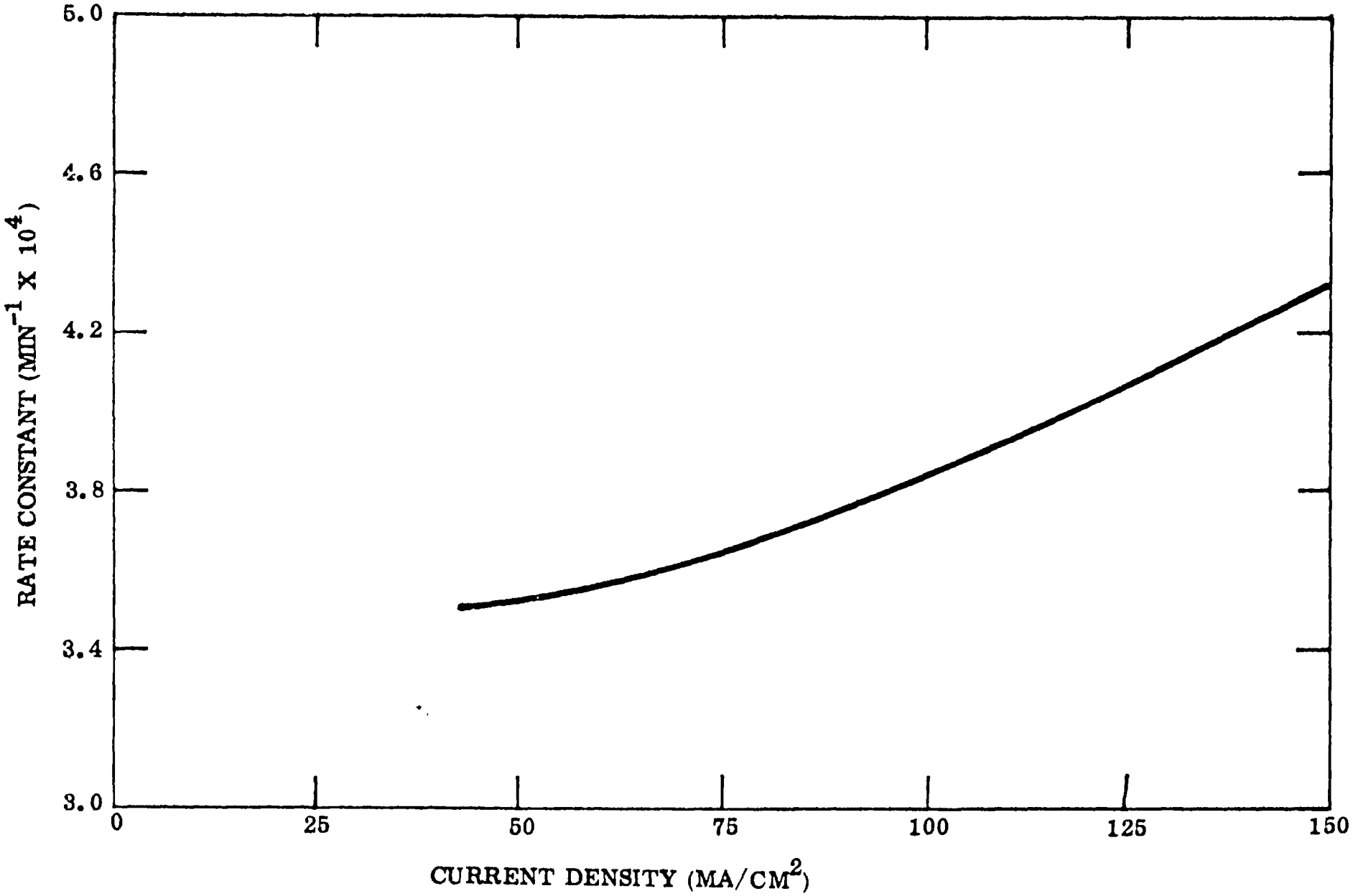


Fig. 2-39 Reaction Rate Constant vs. Current Density

Computer Model Constants. The experimentally determined constants required for the computer model updating, which is described in Section 2.4, were obtained by averaging several data points from Test 3. The analysis is described below.

The volumetric anodic gas generation rate, oxygen plus nitrogen, can be expressed as

$$\dot{U}_T = k\,n\,Y = k\,n\,\frac{I}{A}$$

where

$\dot{U}_T$ = total gas production, cc/min

k = 0.35 (constant)

n = 17 (number of cells)

Y = current density, mA/cm^2

I = current amps

A = 90 (electrode area, cm^2)

Therefore:

$$\dot{U}_T = \frac{(0.35)(17)(10^3)}{90} I = 66.1\,I$$

That portion of $\dot{U}_T$ that is nitrogen can be expressed in terms of the polaragraphically measured effluent PO_2 and the total pressure of the effluent gas as

$$\dot{U}_{N_2} = \left(\frac{P_T - PO_2}{P_T}\right)_{\text{effluent}} \dot{U}_T \qquad (2.7)$$

At the point in the system where effluent PO_2 is measured, the effluent gas pressure is the same as the cabin total pressure.

The empirical formula for $\dot{U}_{N_2}$ is of the form

$$\dot{U}_{N_2} = a\,n\,C + b\,n\,C\,Y \tag{2.8}$$

or

$$\dot{U}_{N_2} = a\,n\,C + b\,n\,C\,\frac{I}{A} \tag{2.9}$$

Inserting known values, this becomes

$$\dot{U}_{N_2} = 17\,a\,C + 189\,b\,C\,I \tag{2.10}$$

Combining the two equations for $\dot{U}_{N_2}$ results in the expresssion

$$66.1\,I\,\frac{P_T - PO_2}{P_T} = 17\,a\,C + 189\,b\,C\,I \tag{2.11}$$

Because the hydrazine concentration does not change rapidly with time while the current is cycling every few minutes, as was shown in Fig. 2-38, it is possible to make a hydrazine concentration determination and record a set of both high and low currents and high and low PO_2 effluents essentially at that concentration. The values of the constants a and b can then be determined by solving a simple set of two simultaneous equations in two unknowns.

Several data points were taken during Test 3 in the manner described above. The experimental data and the resulting values of the constants are shown in Table 2-12. The averages of these values are:

$a = 4.77$

$b = 0.0134$

Table 2-12

EXPERIMENTAL CONSTANTS DETERMINATION

Elapsed Time (hr)	C[(a)]	Current, I (A)		Partial Pressure, PO_2		Constants	
		High	Low	High	Low	a	b
0	2.00	12.9	4.30	490	240	4.67	0.0129
6.28	0.78	13.1	4.25	590	500	4.23	0.0153
15.9	2.15	13.3	4.45	470	210	4.88	0.0128
18.2	0.99	13.0	4.5	570	440	5.36	0.0089
37.5	2.17	13.4	4.55	440	160	5.26	0.0177
40.9	0.76	13.25	4.35	590	490	4.87	0.0118
60.0	2.75	13.2	4.5	420	130	4.30	0.0163
64.14	0.83	13.35	4.35	590	490	4.59	0.0114

(a) Concentration of hydrazine.

2.3.3.3 System Analysis

O_2/N_2 Generator System. In general, the performance of this system was satisfactory, as evidenced by the performance data presented previously in this section. However, some problem areas were identified as a result of system testing.

The current regulators that were used to condition 28 Vdc power and provide constant current to the electrolysis cell stack showed a tendency to drift, especially in the high current mode. These are prototype devices that were designed under Contract

NAS1-9728. Their performance could be improved by incorporating temperature compensation and additional filtering.

The performance of the prototype bubble separator used in the system was not satisfactory. By the end of Test 2, the pressure drop across the hydrophilic membrane had increased to the point where the electrolyte flow rate was becoming marginal. The unit was then rebuilt with new membranes before proceeding with the system testing. Although clogging of the membrane with particulate matter may be a partial explanation of the problem, it was also observed, with fresh membranes installed, that the initial pressure drop across the membrane was sufficient to cause nucleation of gas bubbles on the downstream side. While this may only be a materials problem, concurrent effort in a separate program is being directed to a new bubble separator design concept.

Controls. The cabin PO_2 control technique that was tested during this program employs a fixed hydrazine input rate during the portion of the control cycle where nitrogen addition to the cabin is called for. When the cabin PO_2 reaches a minimum set point, the hydrazine feed is shut off.

The hydrazine feed rate is set so that the PO_2 in the effluent N_2/O_2 mixture from the electrolysis module will not be driven below a set minimum. Because of this limitation on hydrazine input rate, the cabin PO_2 overshoots the control band during the long period of time (usually several hours) required to increase the hydrazine concentration in the electrolyte sufficiently to effect PO_2 turnaround. Furthermore, it was found to be difficult to accurately set and maintain the very low flow rate (less than 1 cc/min) required. Because of the modular design concept of the full-scale system, this limitation would remain in the larger system.

Under steady-state conditions, the control of cabin PO_2 achieved in the model system with this technique was acceptable: A typical cycle of cabin PO_2 at a set control band of 2.85 to 2.95 psia in Test 3 took approximately 8 hr with an overshoot to approximately 3.1 psia. However, this control is sluggish and may be a limiting factor in the ability of the system to respond to sudden changes in demand.

A modification in the control technique in which the hydrazine feed rate is increased to allow a fast ramp of the nitrogen output with two additional set points that cycle the hydrazine feed off at minimum effluent PO_2 levels corresponding to the high and low current modes would affect a faster turnaround of cabin PO_2 and substantially reduce the overshoot. The system also would then be less sensitive to the hydrazine feed rate, and extreme accuracy of the flow rate setting would not be necessary.

The results of attempting to operate the system with the total gas demand very close to the minimum total gas generation rate in Test 4 were described previously. In this case, it was attempted to operate with a three-man metabolic load and the baseline cabin leakage. Under these conditions, the cell stack was generating gas, in the low current mode, at 459 cc/min and the metabolic/leak and nitrogen makeup were supposed to be set at 801 and 333 cc/min, respectively. This meant that the net gas out was supposed to be 468 cc/min, or only 9 cc/min more than the generated gas rate.

From these numbers, it can be seen that only a 1-percent error in metabolic/leak flow setting could cause loss of control; and further, that a combined error in metabolic/leak, nitrogen makeup, and cell current of 2 percent would have the same effect. In future tests it would be advisable to incorporate micrometer flow controls and very accurately calibrated flow indicators for high- or low-limit operation.

2.4 COMPUTER ANALYSES

Experimental data from the one-man model system testing were used to revise and update the computer routine model of the system developed previously under NASA Contract NAS1-7706. In order to verify the computer routine, the program was run using average simulated test conditions, and the results were then compared with the actual test performance. Parametric modeling was performed of the hydrazine feed rate, the gas consumption, metabolic demand, and high/low current modes. These efforts are described in this section.

It is noted that the original computer routine and its revision and updating have been documented separately in a Utilization Manual. Therefore the complete program listing and case inputs are not included in this report.

2.4.1 Model Revision

The empirical functions which appear in the computer routine model, their original values, their revised values, and the equation in which they appear are shown in Table 2-13.

The values of α and β were obtained by applying a density conversion to the experimentally determined values of a and b given previously in Section 2.3.3.

The value of γ was obtained by applying a density conversion to the value of K. The value of K was revised to account for the water vapor in the gas and approximately a 1-percent shunt current.

The values of m were taken from the experimentally determined relationship of m to current density shown in Fig. 2-39.

Hydrazine Feed Rate. The effect of hydrazine feed rate on PO_2 control is shown in Figs. 2-40 and 2-41. The hydrazine feed rate in the first case is 8.35×10^{-4} mols/min/cell and 1.16×10^{-3} mols/min/cell in the second case. These figures illustrate

Table 2-13

COMPUTER MODEL REVISIONS

Function	Relation	Initial Value	Revised Value
α	$\alpha = \rho a$	4.25×10^{-3}	5.33×10^{-3}
β	$\beta = \rho b$	2.43×10^{-5}	1.55×10^{-5}
γ	$\gamma = \rho k$	4.35×10^{-4}	4.13×10^{-4}
m_1	$m_1 = f(Y_1)$	3.28×10^{-4} @ 150	4.32×10^{-4} @ 150
m_2	$m_2 = f(Y_2)$	2.52×10^{-4} @ 50	3.52×10^{-4} @ 50

Equations:

$$C_{max\,(1)} = \frac{\gamma Y_1}{\alpha + \beta Y_1}$$

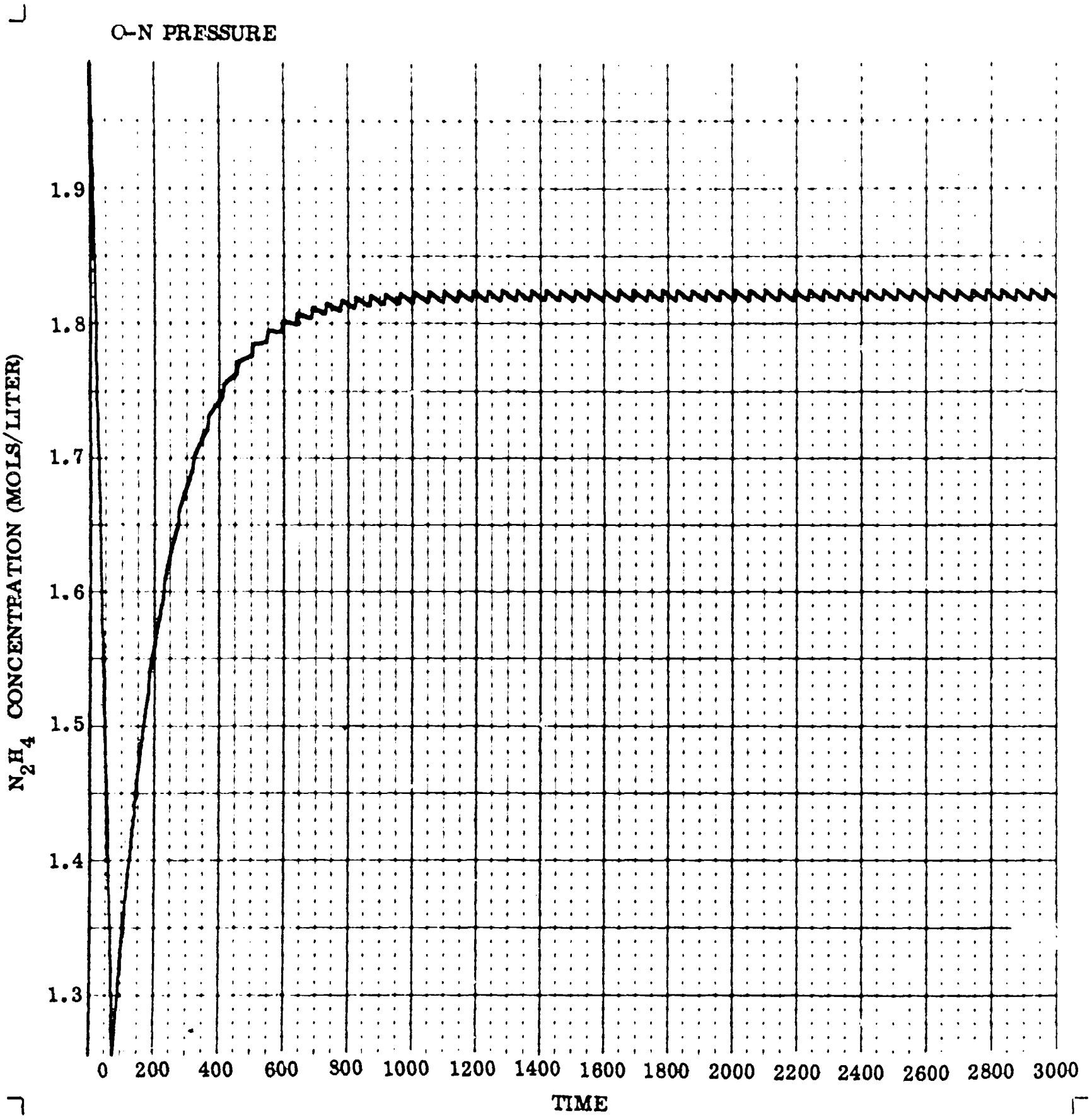
$$C_{max\,(2)} = \frac{\gamma Y_2}{\alpha + \beta Y_2}$$

$$PO_2 = \frac{\lambda O_2\, PO_{2_i} + \left[(\gamma n \cdot Y) - (\alpha n \cdot C) - (\beta n \cdot C \cdot Y) - \left(\dot{m}_{O_{2\,out}}\right)\right]\Delta t}{\lambda O_2}$$

$$P_T = \frac{P_{T_i}\,\lambda T + \left[(\gamma n \cdot Y) - \left(\dot{m}_{T_{out}}\right)\right]\Delta t}{\lambda t}$$

$$C = \frac{X}{m} + \left(C_o - \frac{X}{m}\right) \exp\left(-mn\, t/v\right)$$

the critical effect of hydrazine flow rate on the PO_2 control. In Fig. 2-40, the hydrazine concentration reaches an equilibrium value of 1.82 M, and insufficient nitrogen is being generated to effect turnaround of PO_2. At the higher hydrazine feed rate, in Fig. 2-41, the hydrazine concentration reaches 2.53 M, where sufficient nitrogen is being produced to cause the PO_2 to cycle. The rate constants had not been revised at the time of these computer runs and therefore the cycle time shown in Fig. 2-41 is not representative.



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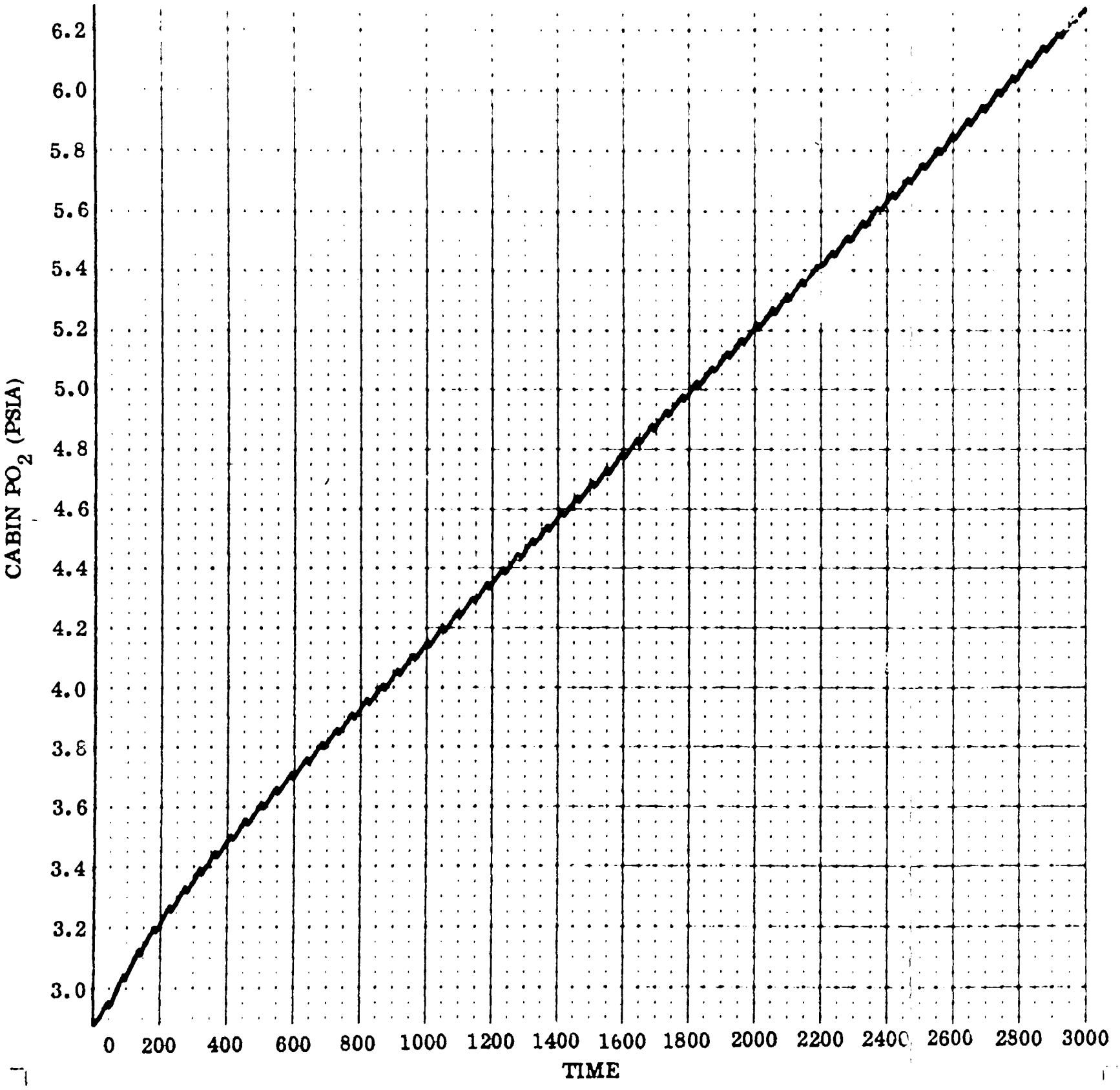

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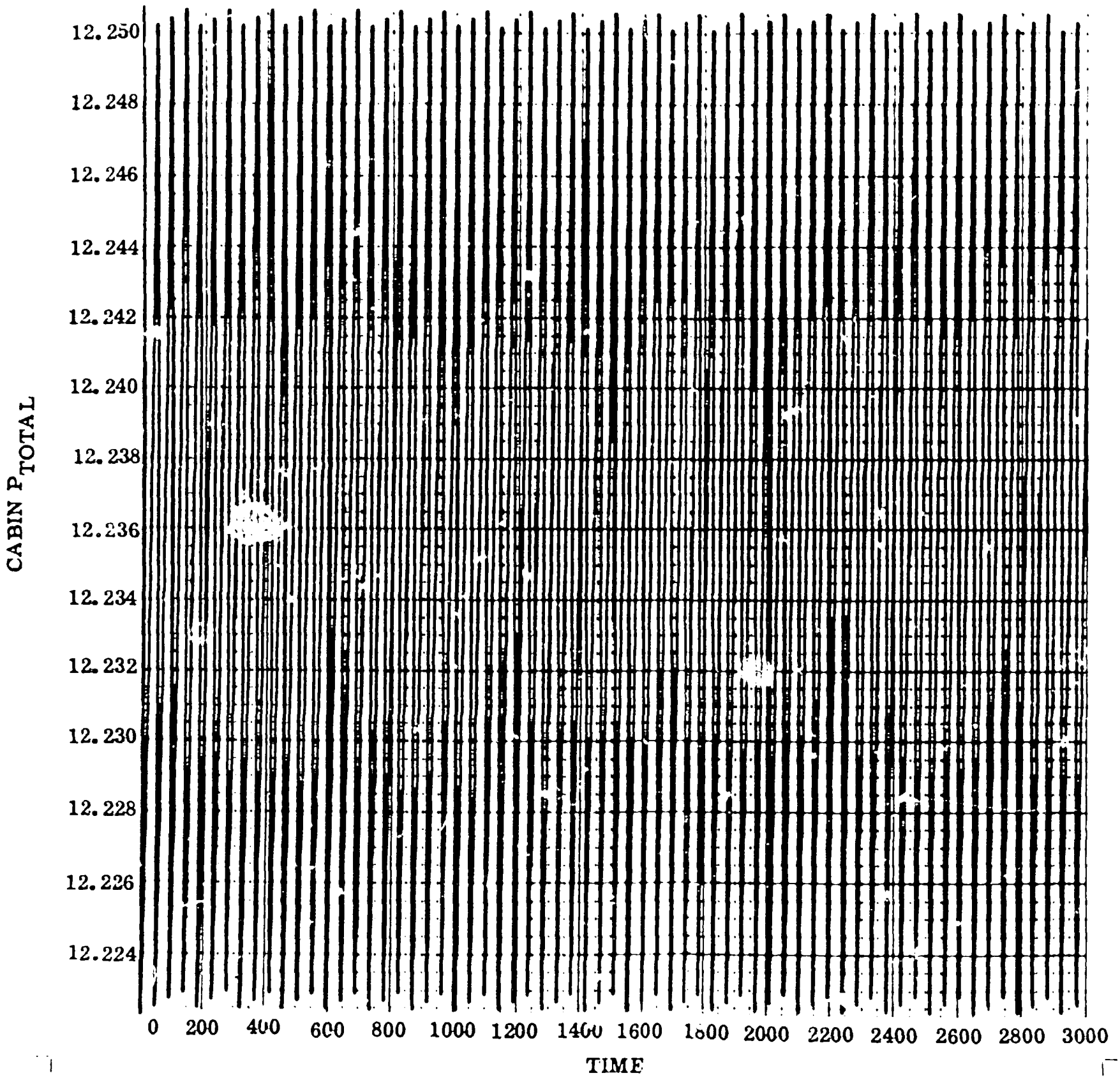

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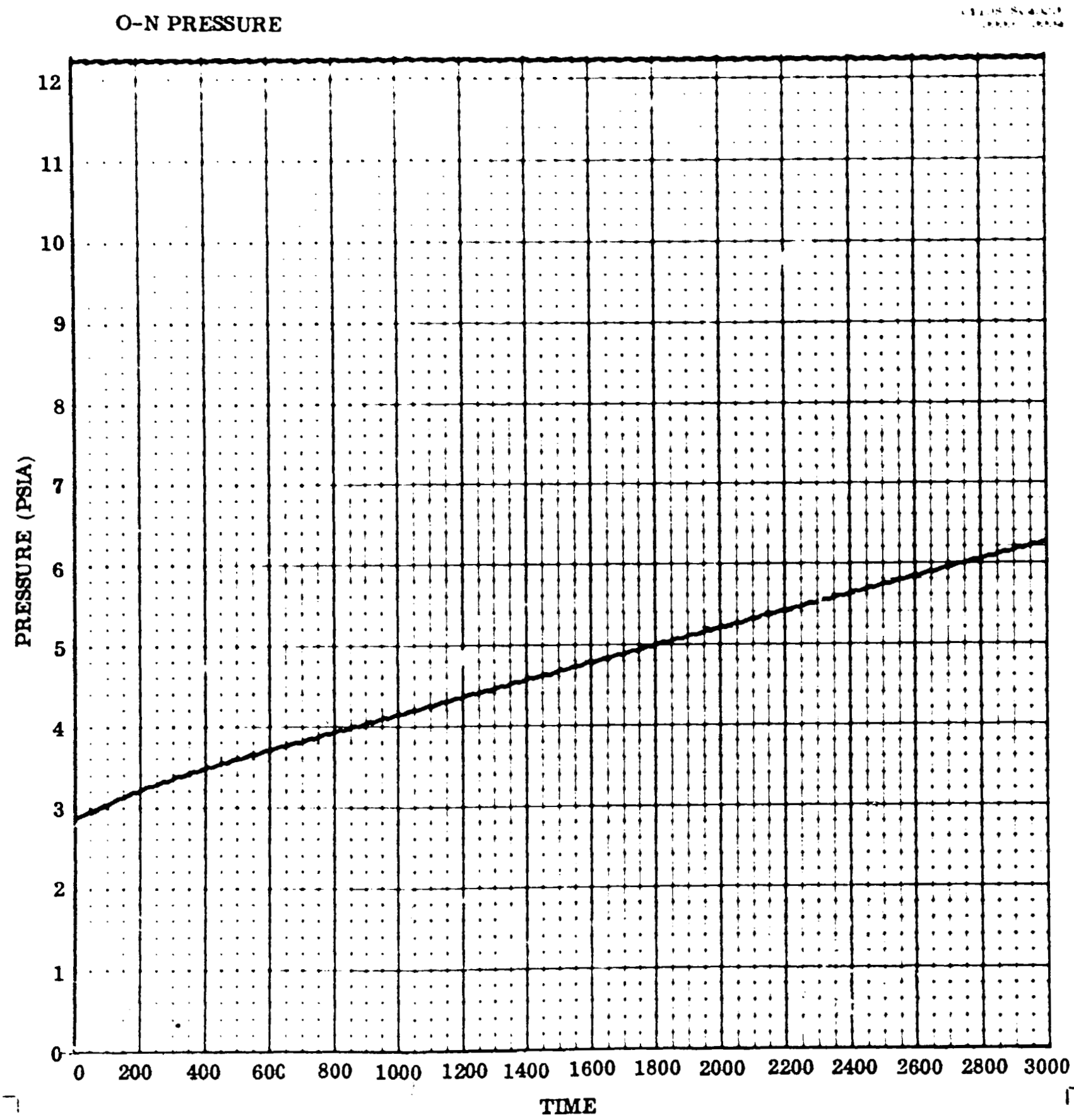

Fig. 2-40 Initial Run of Revised Computer Routine

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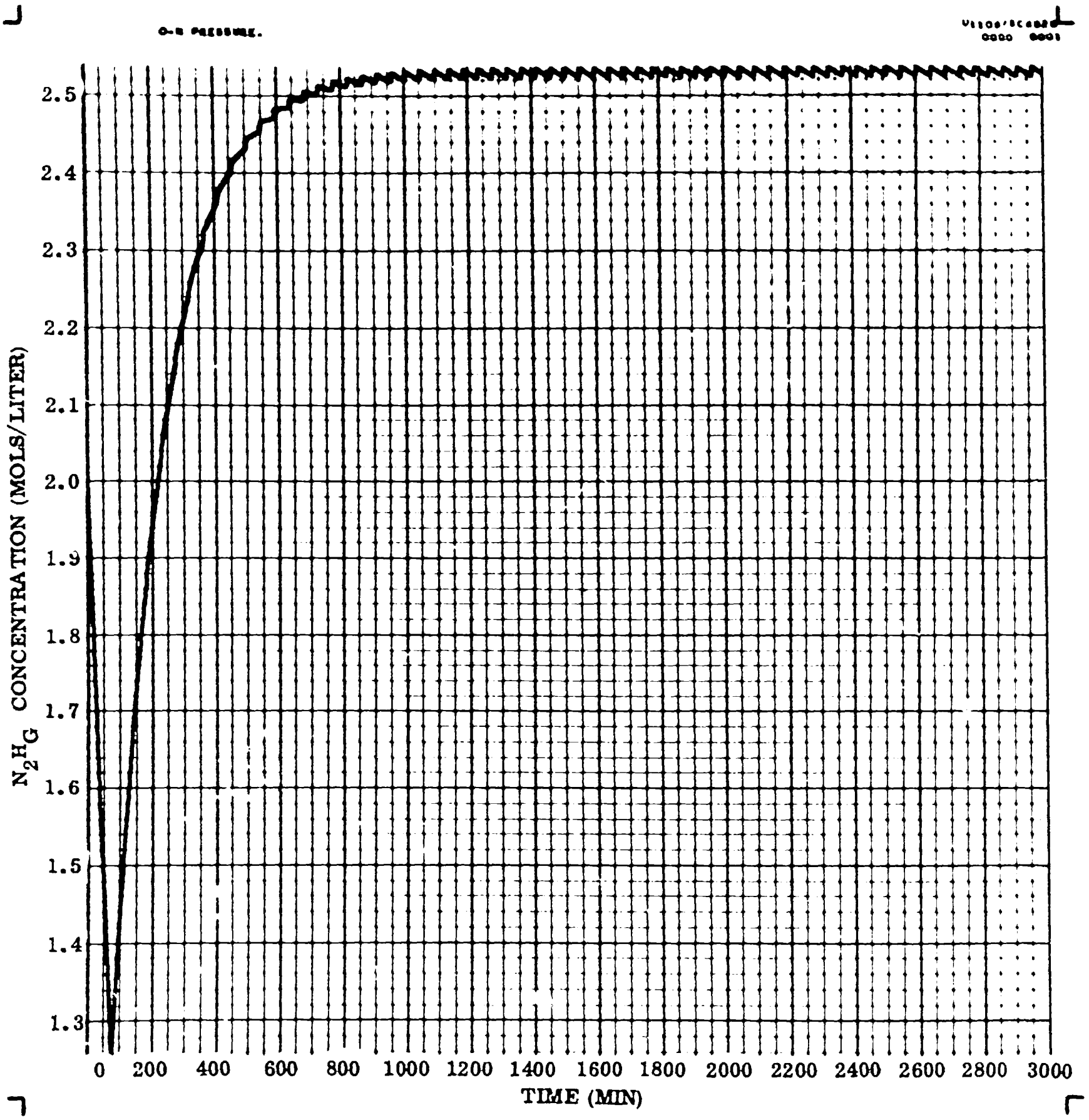

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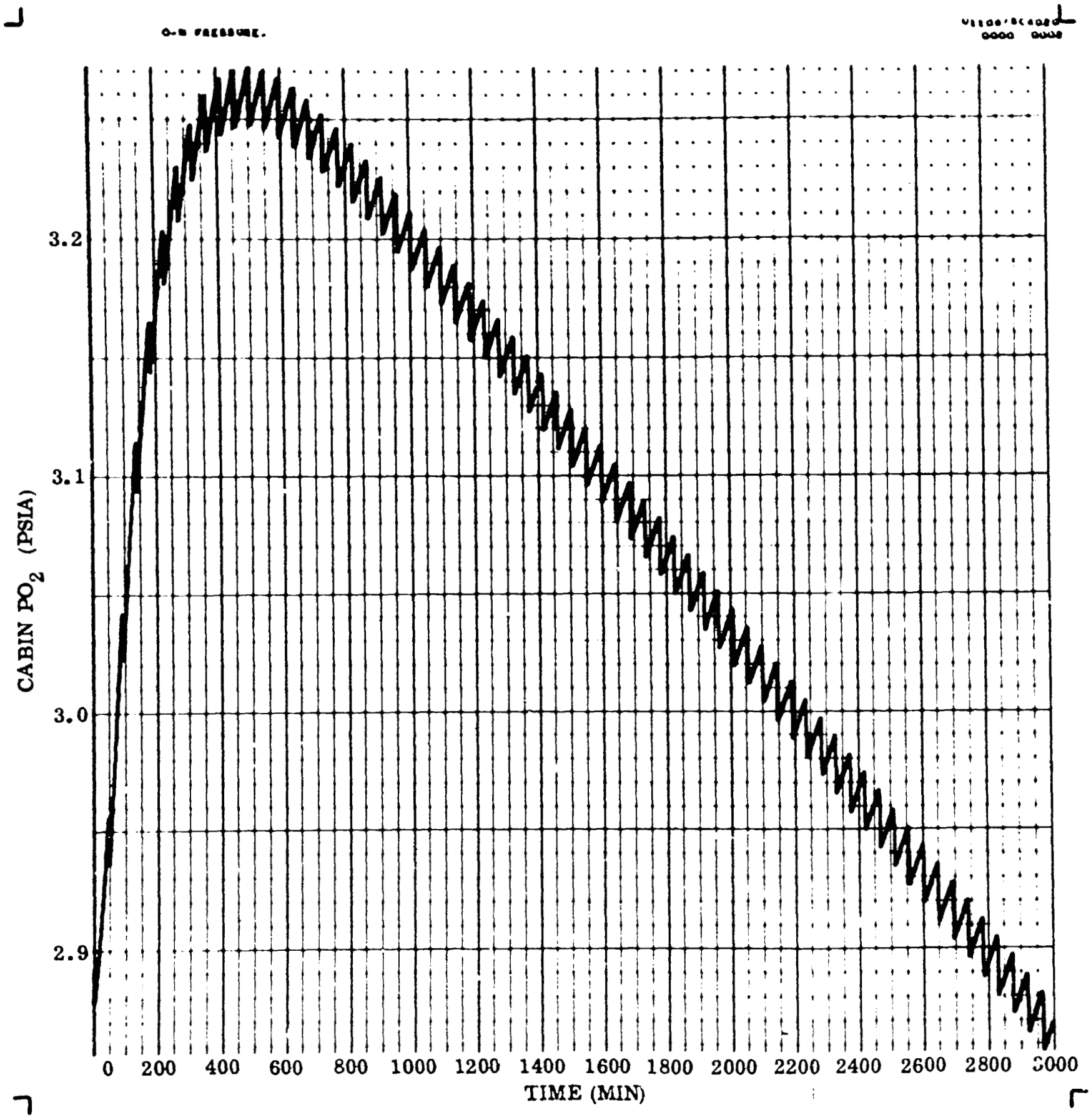

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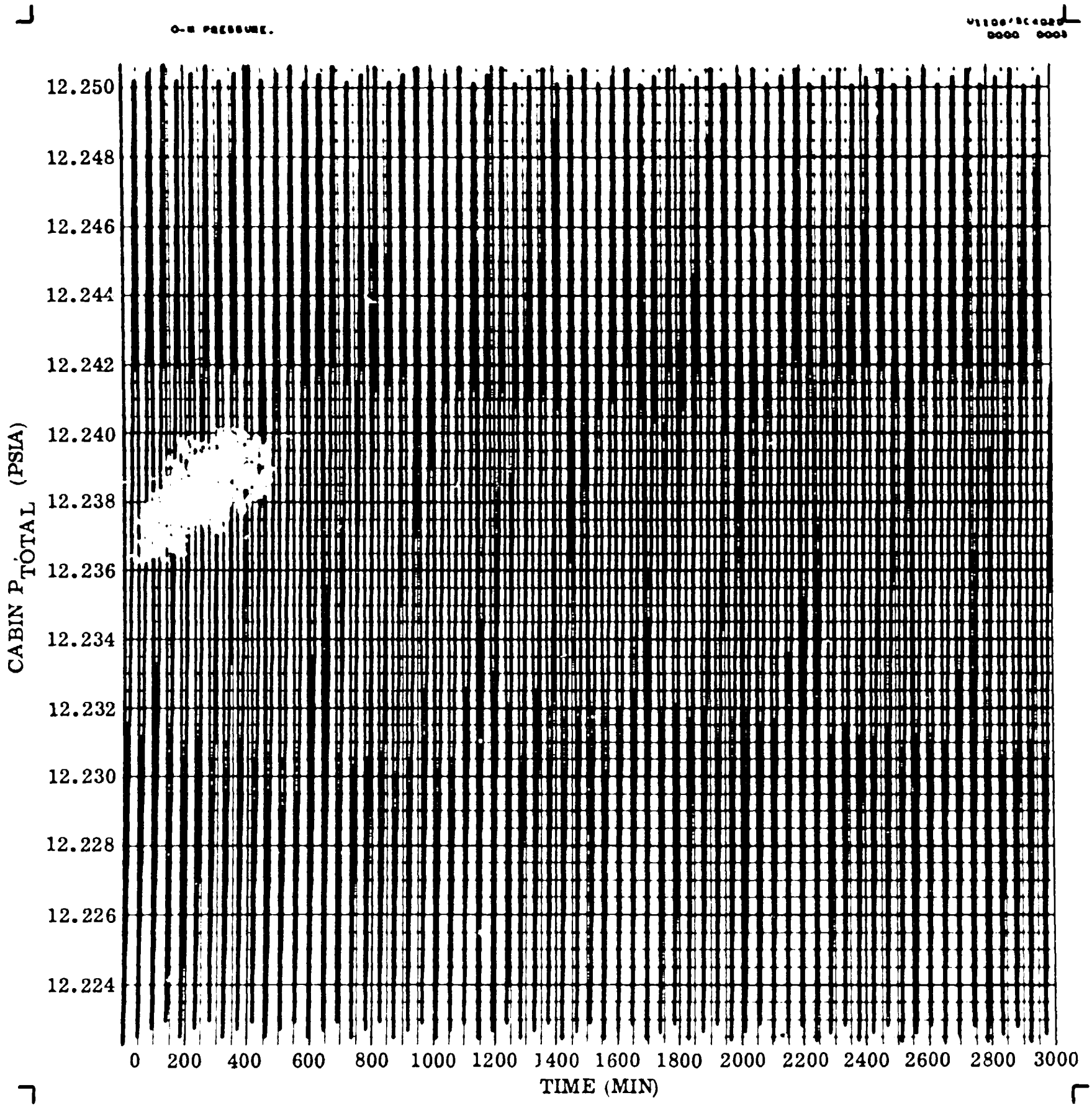

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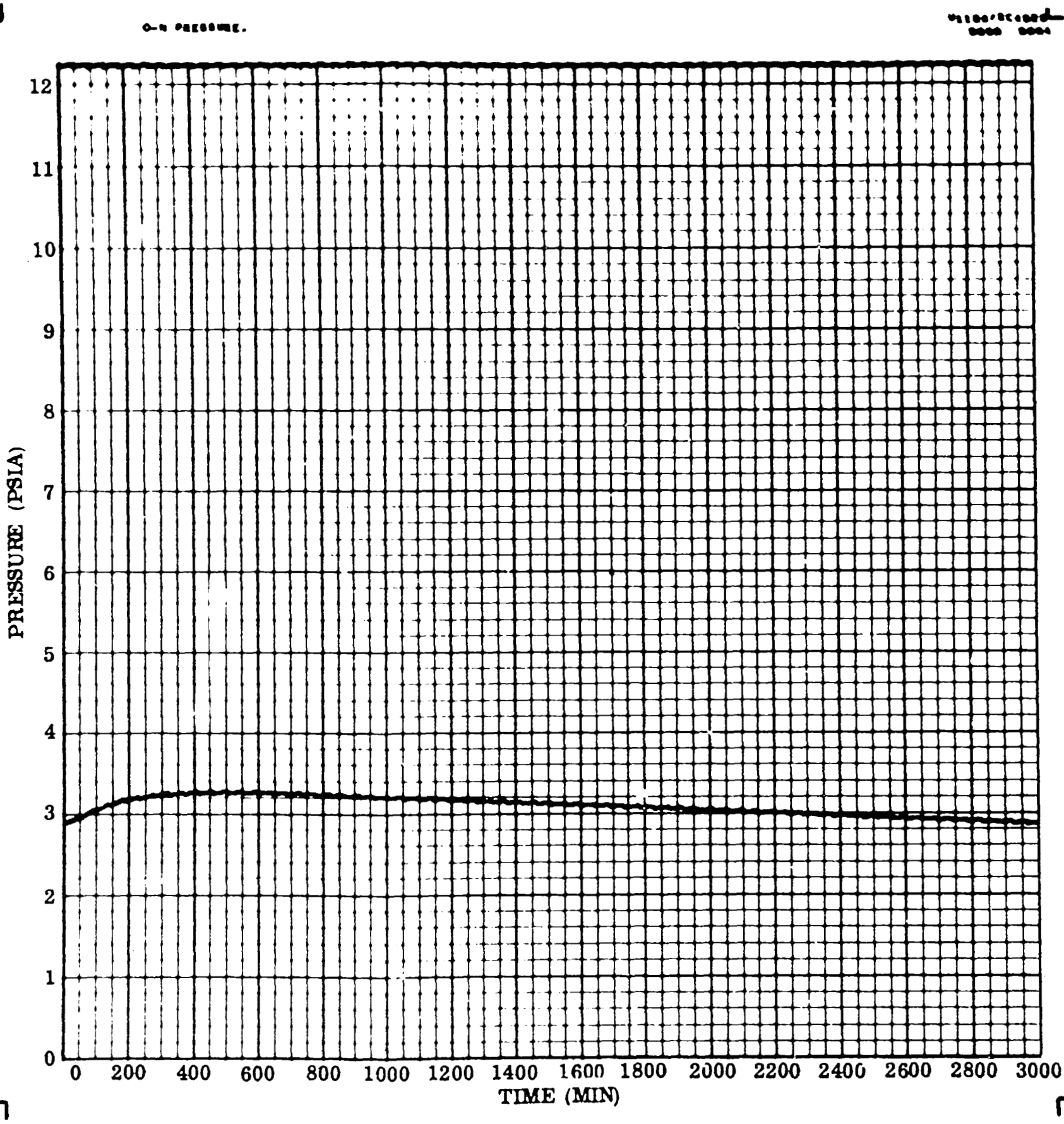

Fig. 2-41 Effect of Increased Hydrazine Feed Rate

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Test 3 Conditions. Several runs were made simulating the conditions of Test 3. Because many of the system parameters varied with time, average values of the parameters were used in the computer runs. The averaging process introduces small errors in that it assumes a linear relationship between current and rate constant. The best match that was achieved in three runs is shown in Fig. 2-42. The envelope and characteristic of the PO_2 control are in good agreement with the Test 3 data (cycles 1, 2, 3, 5, and 6 of Test 3 are plotted).

In order to achieve agreement on mass balance, the computer case input for $\dot{m}_{T_{out}}$ had to be decreased by approximately 10 percent. This is indicative of a combination of inaccuracies in metabolic/leak and nitrogen makeup instrumentation. This problem area was discussed previously in Section 2.3 under system analysis.

2.4.2 Chaining

The versatility of the computer routine was increased by adding a chaining capability. This makes it possible in a single run to handle a sequence of step changes in case inputs. In effect, step changes in inputs during the run recycle the time base to make the conditions of P_T, PO_2, and C at time = t become the initial conditions for the next time interval.

A computer run was made simulating the step changes of a portion of Test 4. The results are shown in Fig. 2-43. As with the simulation of Test 3, the envelope and characteristics of PO_2 control are in good agreement, and the differences in cycle rate are attributed to errors introduced by the averaging process. The computer case input values for this run are given in Table 2-14. The case inputs are described in Ref 1. The points in the run where the step changes were made are indicated in Fig. 2-43.

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2.4.3 Space Station Orbital Simulation

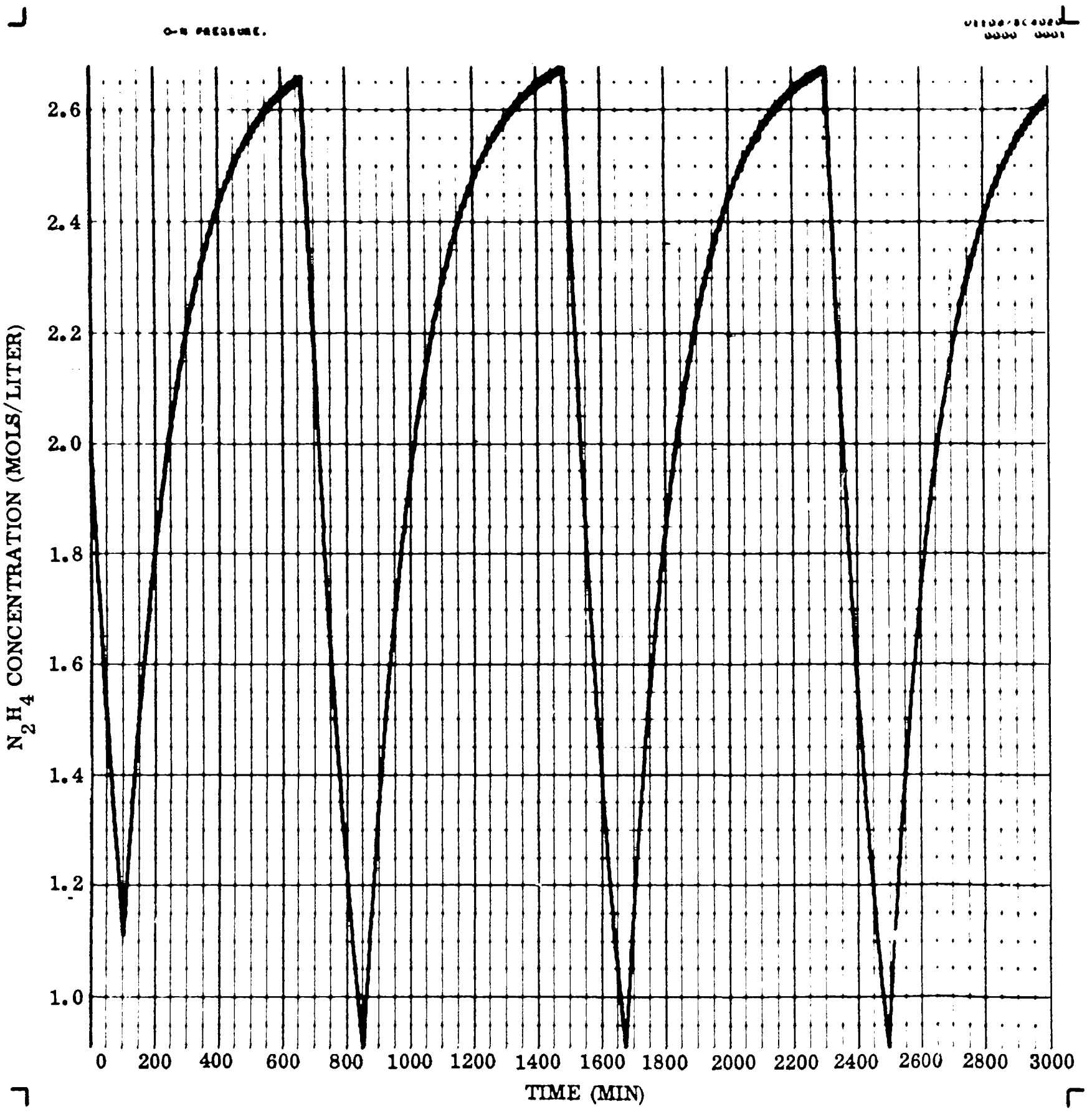
As part of the preliminary design of a 12-man O_2/N_2 system for space station use, the computer routine was used to predict the control characteristics. A 94-min orbit with 58 min of daylight and 36 min of darkness was used. The high/low current mode on the sunlight side was set at nominal ±10 percent and on the dark side at 50 percent of nomial. Fifty-three orbits are shown in Fig. 2-44. The long time constant shown for the PO_2 control cycle indicates a need for the development of a more responsive PO_2 control technique.

Table 2-14

COMPUTER RUN 2-45 – CASE INPUTS

Run No.	T_0	T_{Max}	PO_2 I	P_{tot} I	DMO_2 Out	DM_{tot} Out	C_0	X_2
2-45a	0	1,020	2.82	12.26	0.55	0.75	1.48	1.4×10^{-3}
2-45b	1,020	1,110	–	–	0.31	0.51	–	1.37×10^{-3}
2-45c	1,110	2,040	–	–	0.27	0.53	–	1.37×10^{-3}
2-45d	2,040	2,325	–	–	0.37	0.68	–	1.15×10^{-3}

Run No.	Y_1	Y_2	M_1	M_2
2-45a	152	76	4.35×10^{-4}	3.66×10^{-4}
2-45b	153	72	4.36×10^{-4}	3.61×10^{-4}
2-45c	150	77	4.32×10^{-4}	3.66×10^{-4}
2-45d	153	74	4.36×10^{-4}	3.64×10^{-4}



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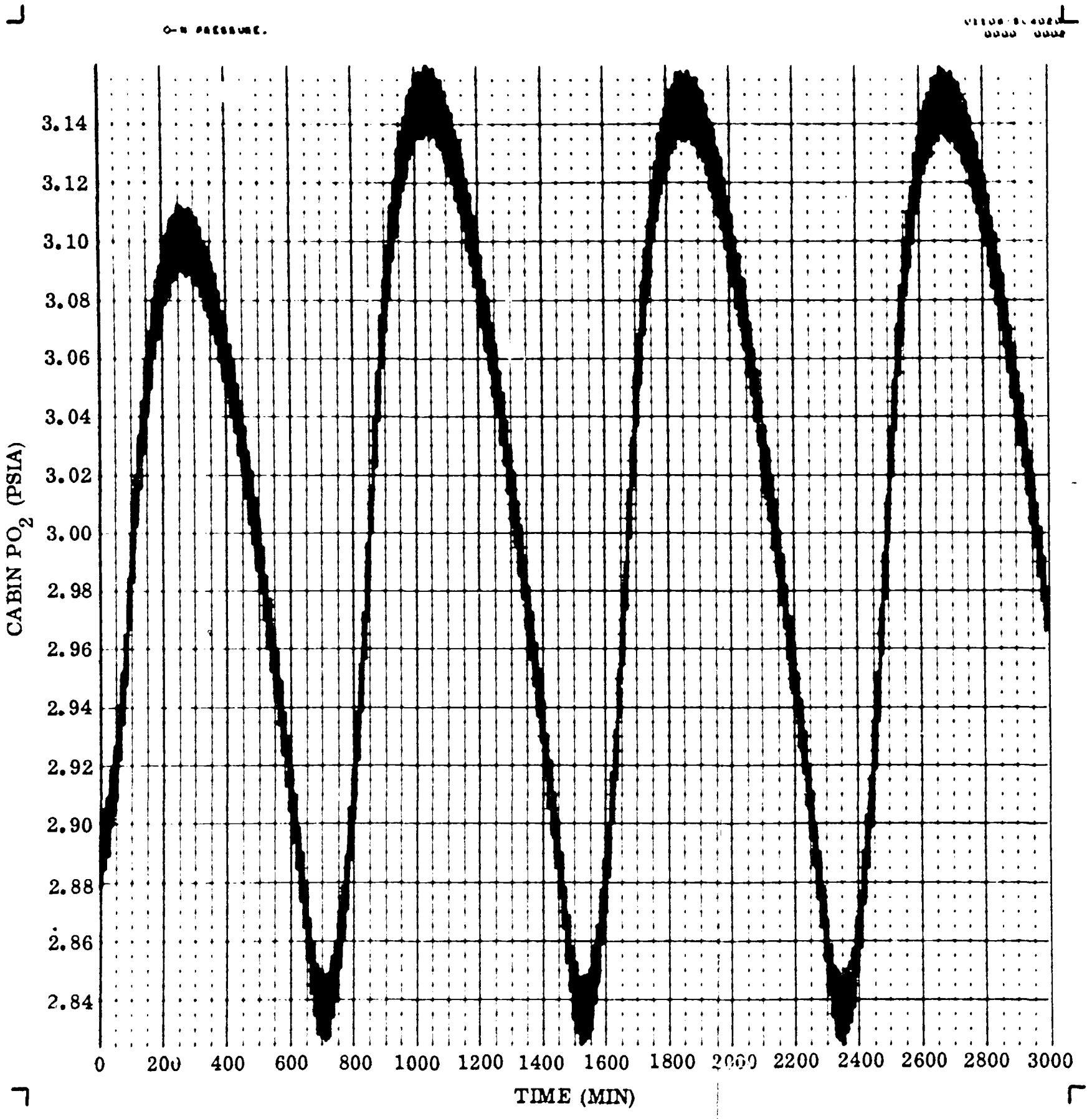

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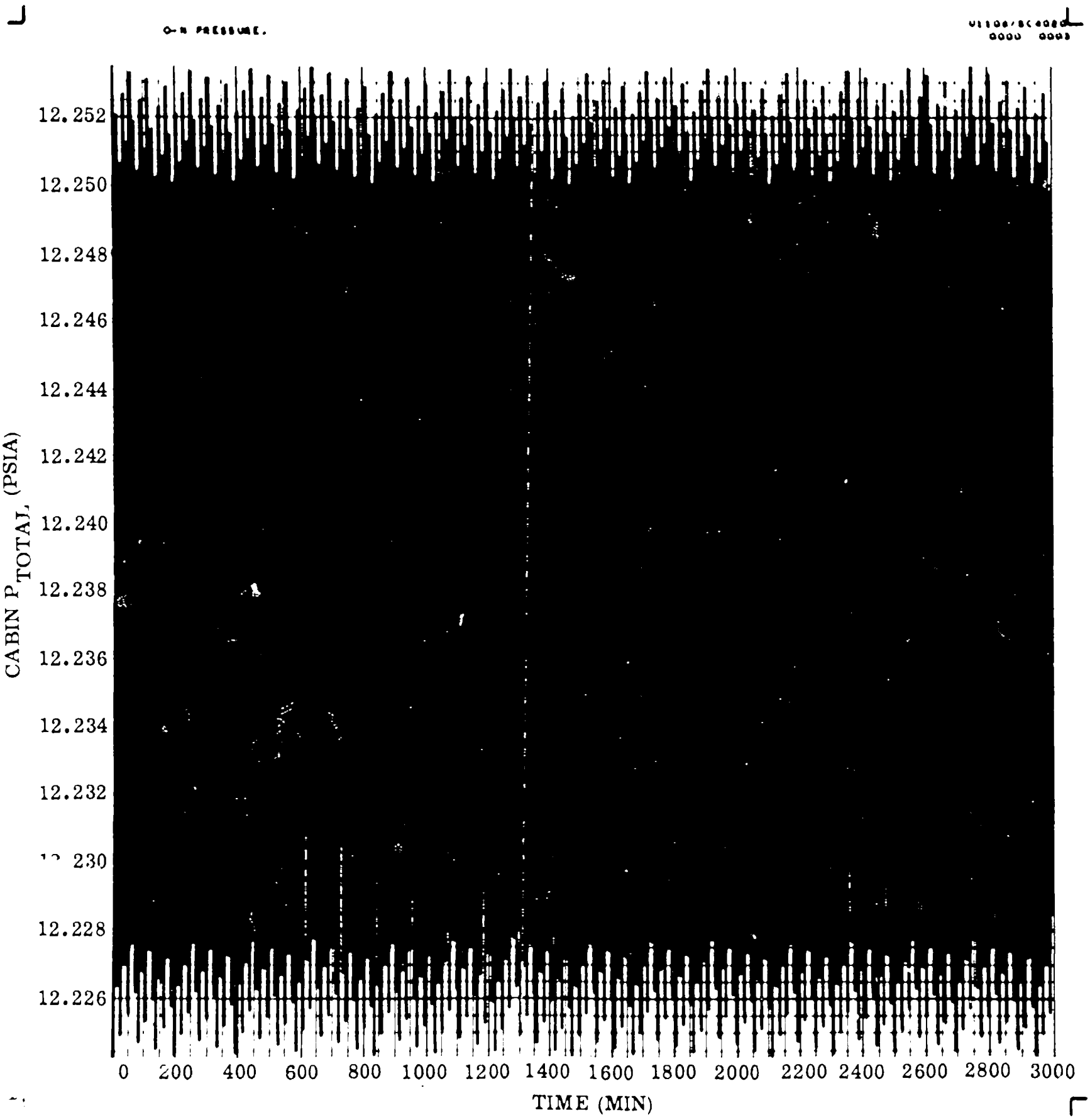

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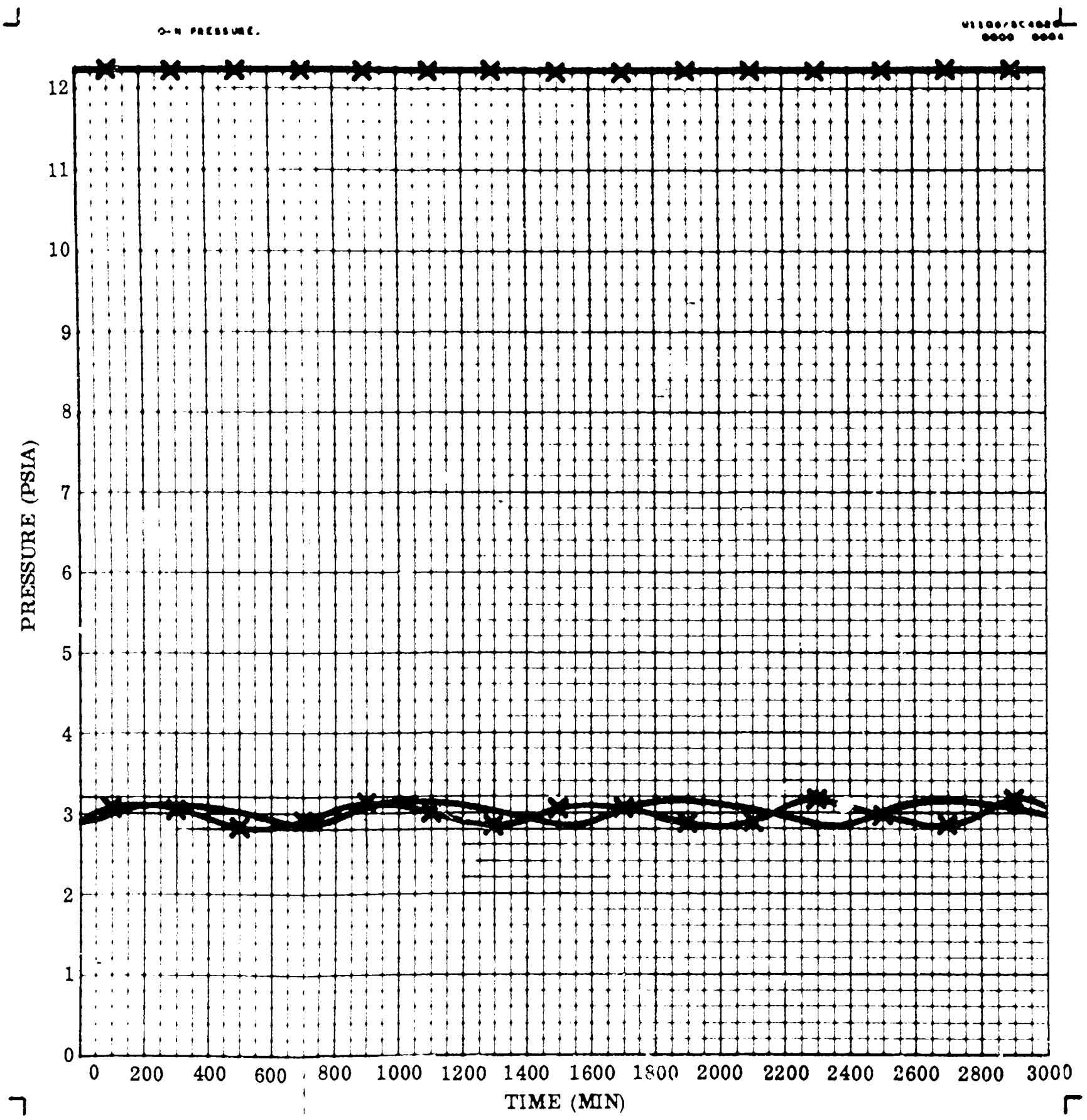

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Fig. 2-42 Test 3 Simulation

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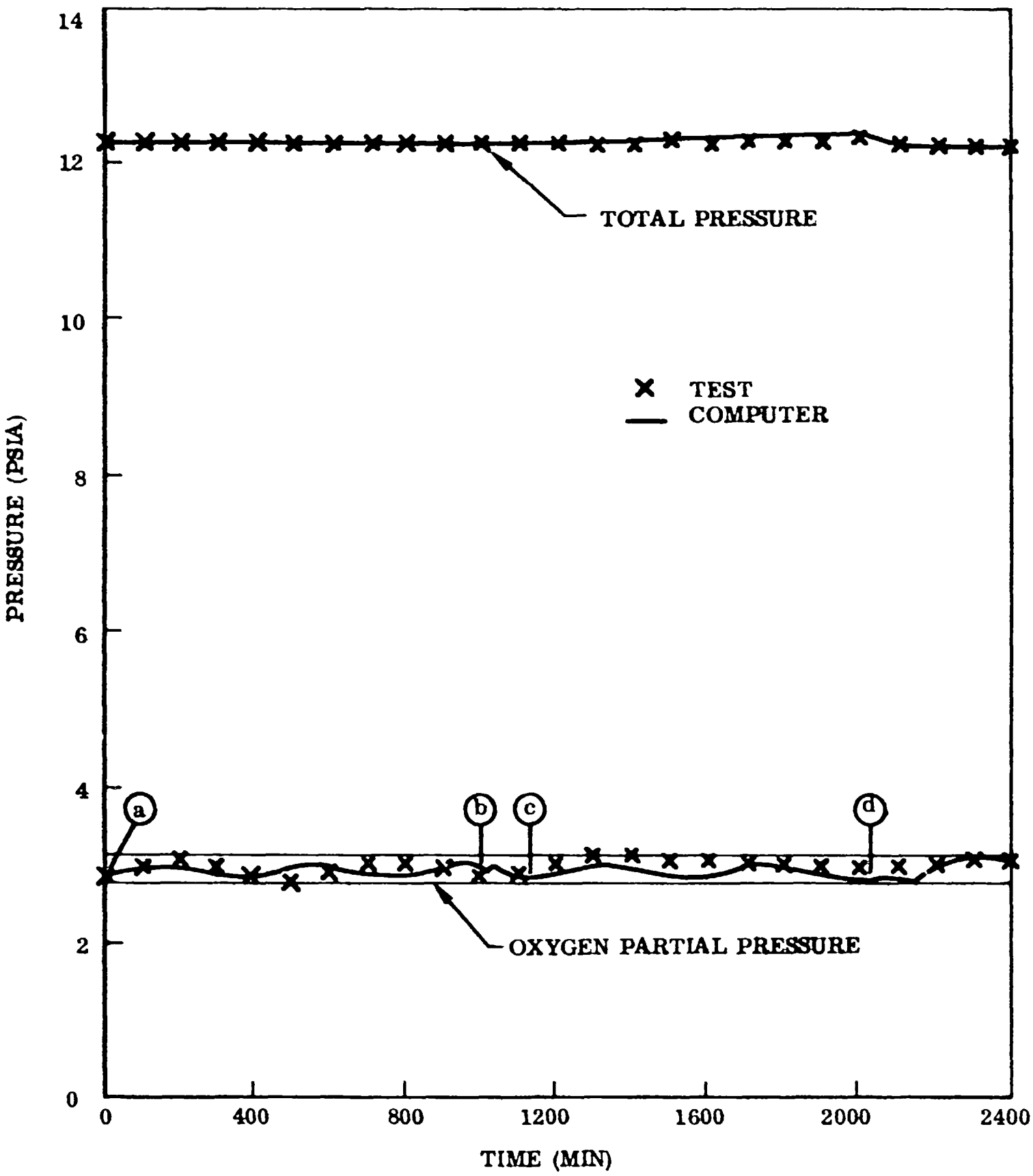

Fig. 2-43 Test 4 Simulation

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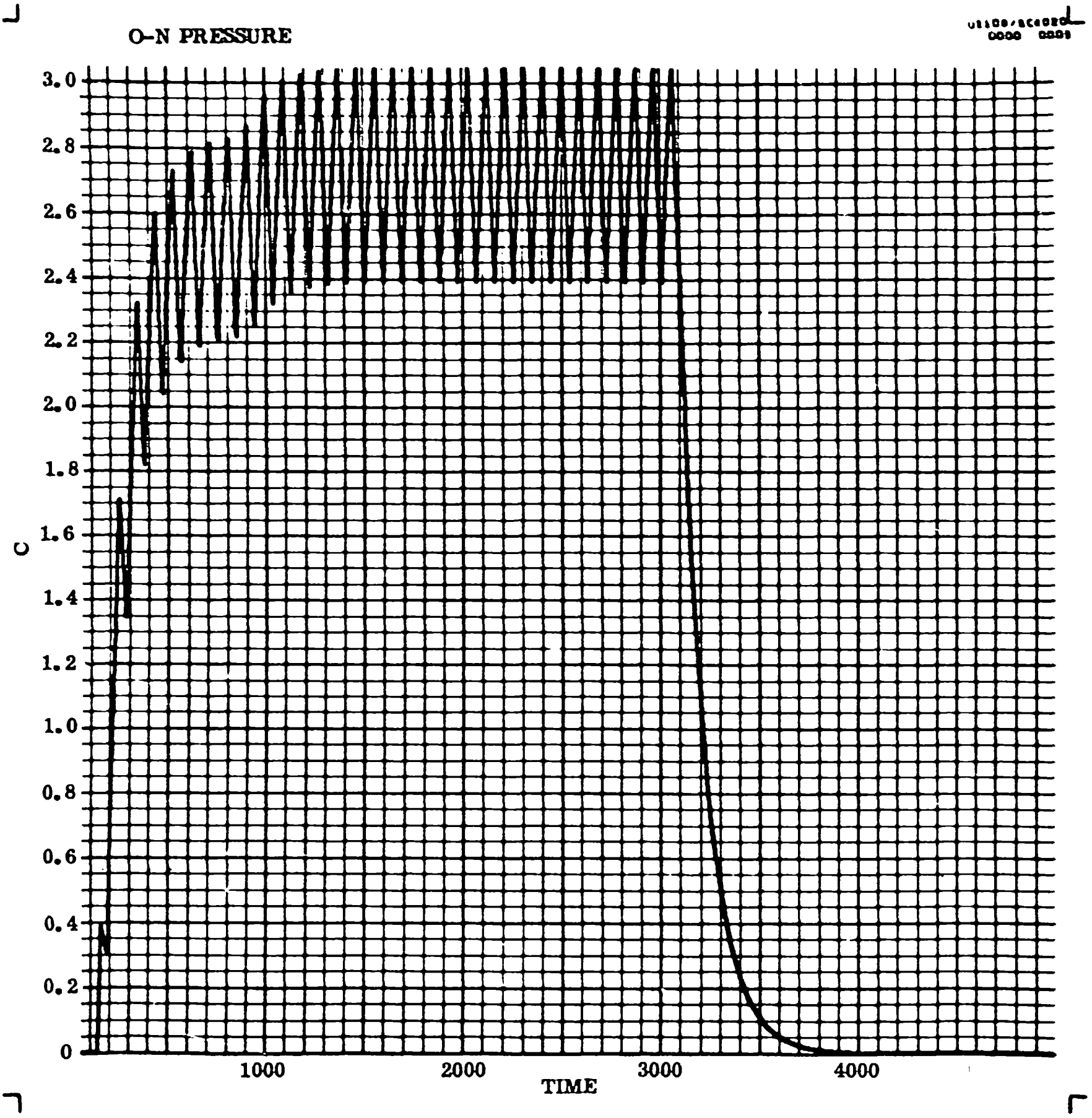

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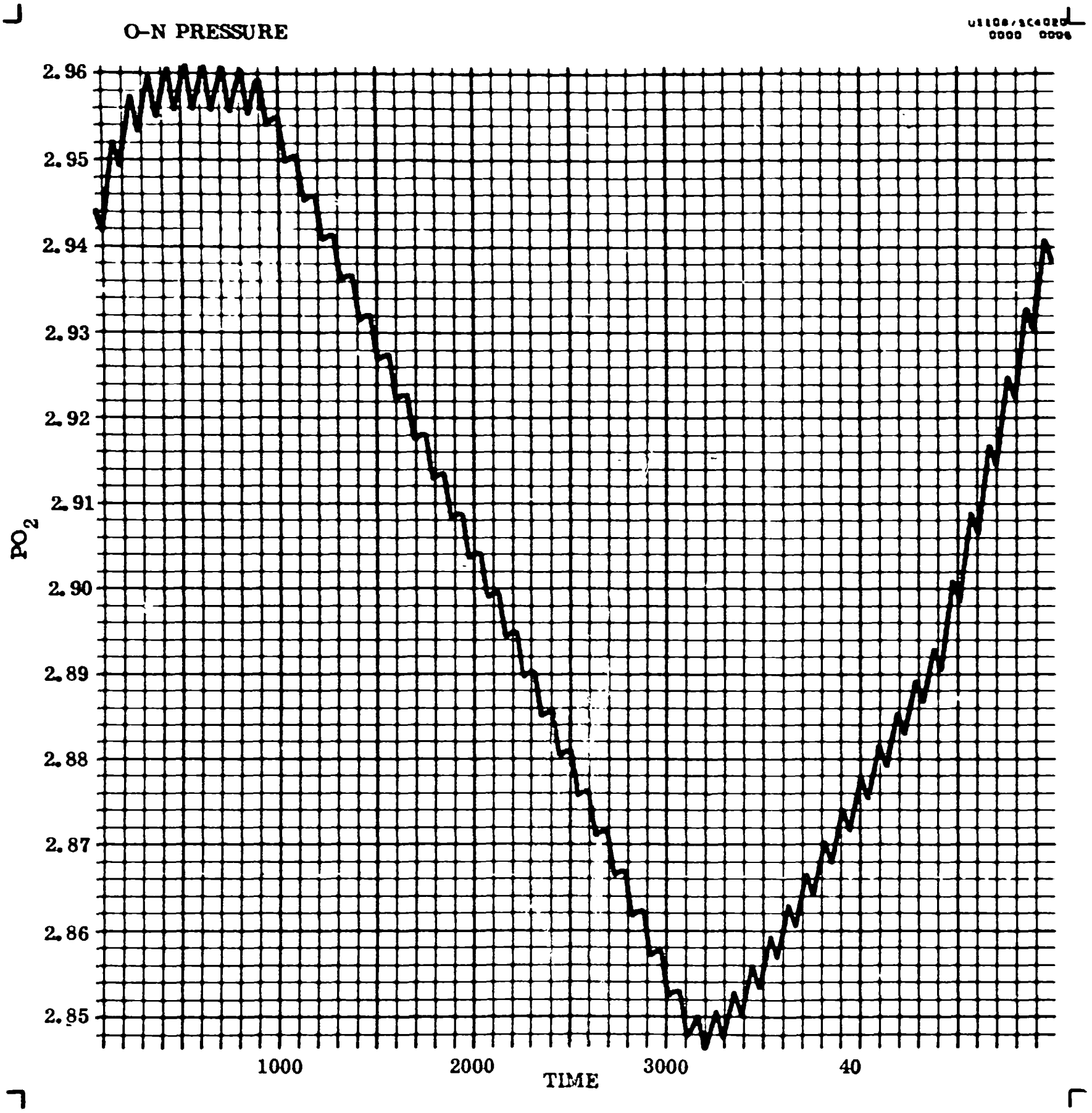

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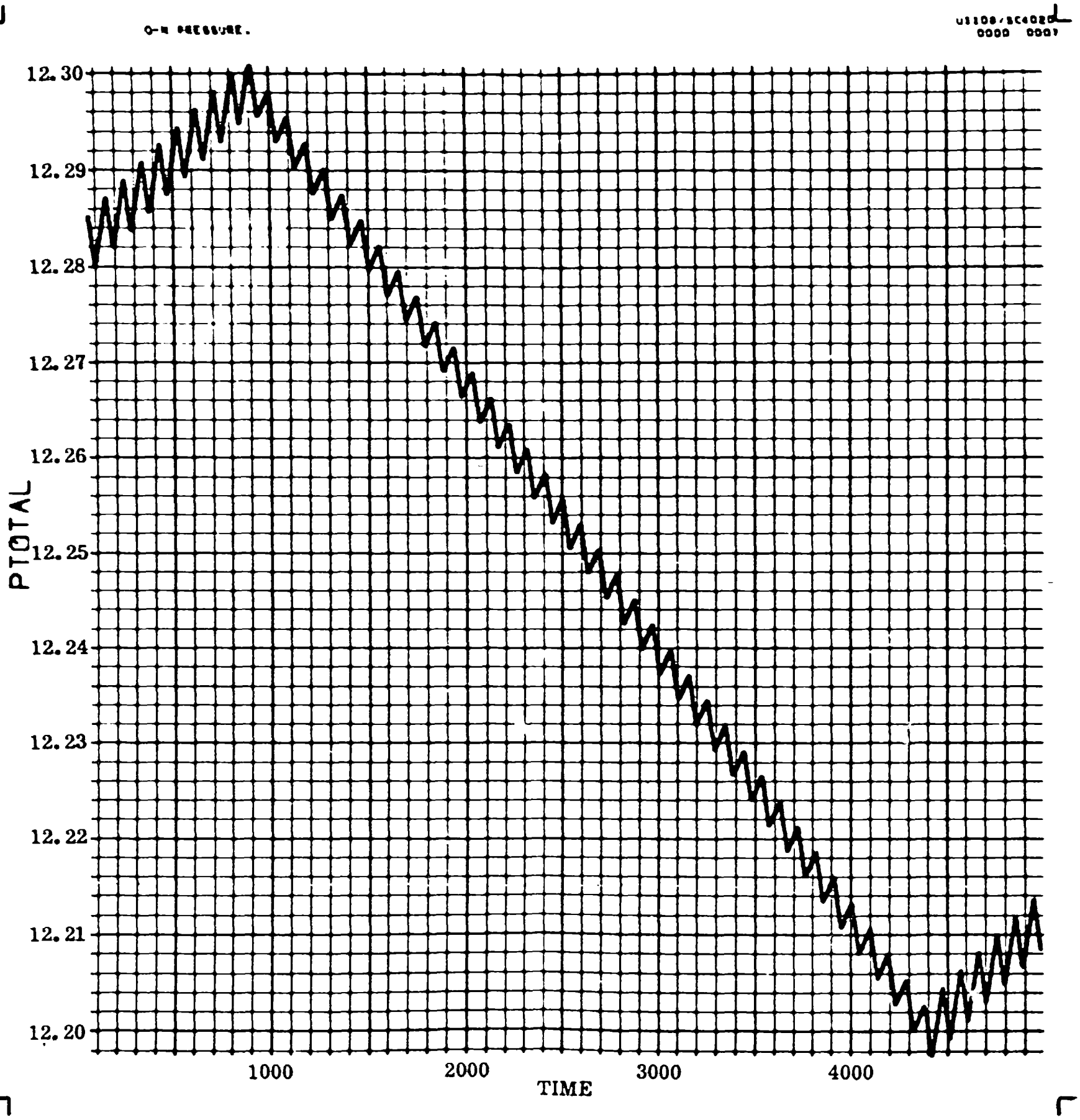

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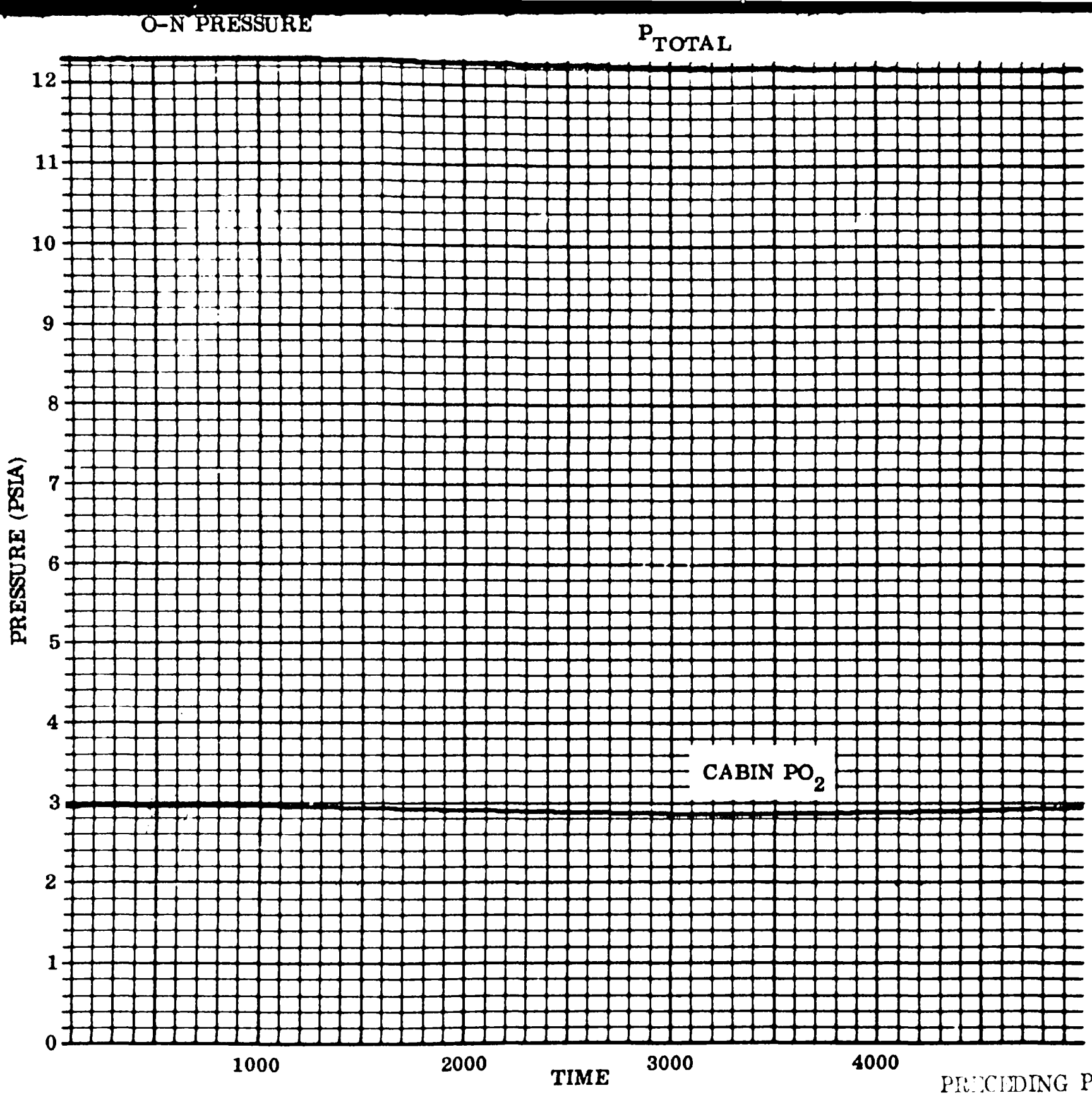

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Fig. 2-44 Space Station Orbital Simulation

2.5 PRELIMINARY SYSTEM DESIGN

The preliminary design of a full-scale, 12-man oxygen/nitrogen generation system was conducted under this program utilizing the experimental data described in this report as a basis.

The preliminary design package included performance specifications, preliminary design layout drawings, interfaces and packaging, and supporting system analyses. A summary description of the preliminary system design and performance specification is presented in the following paragraphs.

2.5.1 PD System Description

In developing the design approach for the hydrazine water electrolysis system, the first consideration was an appropriate maintenance concept. Maintenance analysis revealed that the best approach was to avoid breaking into the electrolyte circuit to perform any maintenance tasks. This approach eliminates the necessity for handling the electrolyte in zero gravity and can be implemented with no significant weight penalty. The maintenance concept that was evolved consists of providing individual, self-contained hydraulic assemblies with no electrolyte connections; the electrolyte flow circuit is completely internally manifolded. These assemblies, or modules, are completely sealed to eliminate electrolyte leakage.

A reliability analysis was conducted to determine the optimum size and number of these individual modules. Various sizes and, hence, various numbers of modules were considered, ranging from one to nine active modules required for the 12-man capacity. Each module was first optimized in terms of redundant components to a point where no significant increase in reliability could be achieved by adding additional redundancy. The total number of modules, active plus spares, required to achieve a reliability goal of 0.9980 was then determined. These various systems were examined to determine which system required the least total weight.

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The analysis showed that a system employing nine active modules and five spare modules has the lowest weight. The approach to packaging these modules in a swing-out cabinet was to install 12 modules – nine active plus three installed spares – as shown in the Frontispiece of this report. The modules are mounted on rails to allow for easy installation and removal. Disconnects are provided in the rear of each module for the oxygen/nitrogen and hydrogen effluent gases, supply water and hydrazine, and the nitrogen required for pressurization. With this design, no electrolyte fittings need to be disconnected to replace a module. The cooling required for each module is provided by a conduction cold plate that interfaces between the module and the cabinet.

The swing-out cabinet also contains individual replaceable electronic assemblies for each module, water conditioning equipment, and a central status panel so that data supplied to the onboard computer system can be manually monitored.

The complete system to support 12 men for 180 days at the nominal metabolic and leakage rate with a reliability of 0.9980 requires a maximum of 7,830 watts of power and has a total fixed weight of 862 lb, including spares. The weight of an individual replaceable module is 46.6 lb.

2.5.2 Summary System Specification

A summary of important performance parameters is presented in Table 2-15. The data presented include input power, waste-heat rejection rates, and inlet and outlet flow rates and pressures. Flow rates so noted represent the day-night average. Included are data for the nominal and the maximum cabin leak rates.

Table 2-15

SUMMARY SYSTEM PERFORMANCE SPECIFICATION

Aspect	Nominal	Maximum
Oxygen generation rate (lb/day)[(a)]	26.1	33.2
Nitrogen generation rate (lb/day)[(a)]	8.0	22.6
Hydrogen generation rate (lb/day)[(a)]	4.75	7.59
Water consumption (lb/day)[(a)]	29.3	37.3
Hydrazine consumption (lb/day)[(a)]	9.72	27.5
Power consumption		
Day (unregulated 40 to 60 Vdc)(W)	7,830	13,300
Night (regulated 28 Vdc)(W)	3,180	5,160
Heat rejection		
Day (Btu/hr)	13,700	23,900
Night (Btu/hr)	4,720	7,960
N_2 supply (lb/day)	0.07	0.09
Output pressure, H_2 and O_2/N_2, variable (psia)	1 to 12	1 to 12
Operating temperature (° F)	75	75
Number of active modules	9	12
Total system weight, with spares (lb)	862	862
Weight of replaceable module (lb)	46.6	46.6

[(a)]Day-night average

Section 3
CONCLUSIONS

3.1 ELECTRODE DEVELOPMENT

Experimental electrodes were developed with performance comparable to the commercial material used in previous programs. Their suitability for use in a hydrazine electrolysis system was demonstrated by the performance of three of these electrodes as anodes in the one-man model O_2/N_2 system testing. Exploratory testing of reduced-catalyst cathodes also indicated an approach to improvement in hydrazine reaction efficiency.

3.2 ONE-MAN MODEL O_2/N_2 SYSTEM

The one-man model O_2/N_2 generator integrated with a cabin and metabolic/leak simulator provided an excellent testbed for evaluating the hydrazine water electrolysis approach to a noncryogenic O_2/N_2 generation system. Significant data concerning component performance, system control techniques, and cabin atmosphere control characteristics were obtained. Adequate control of the cabin simulator total pressure and oxygen partial pressure were demonstrated.

3.3 COMPUTER MODEL

The computer routine model, developed under Contract NAS1-7706, was revised and updated based on the system test data. Reasonable agreement was obtained between the test and computer prediction of space cabin atmosphere control. The revised computer routine predicts adequate control of a full-scale 12-man space station cabin.

3.4 PRELIMINARY SYSTEM DESIGN

A preliminary design effort with emphasis on maintainability, reliability, a sound basis of experimental data and proven concepts resulted in the preliminary design and specification of a 12-man O_2/N_2 generation system suitable for space station use. The complete system to support 12-men for 180 days at the nominal metabolic and leakage rate with a reliability of 0.9980 requires a maximum of 7,830 watts of power and has a total fixed weight of 862 lb, including spares. The weight of an individual replaceable module is 46.6 lb. The system is capable of handling a maximum cabin leakage of 33.7 lb/day.

Section 4

REFERENCES

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2. -----, Preliminary Design of a Space Station Electrolytic Oxygen-Nitrogen Generator, by B. M. Greenough, LMSC-A977498, Sunnyvale, Calif., 5 Mar 1971

3. W. J. Conner, B. M. Greenough, and G. M. Cook, "Design and Development of a Water Vapor Electrolysis Unit," NASA CR 607, Sep 1966

4. R. G. Haldeman, "Electrode-Matrix Materials," reprinted from 21st Annual Proceedings Power Sources Conference, May 1967

5. B. M. Greenough, "The Development and Preliminary Design of an Oxygen-Nitrogen Generation System," NASA CR 66940 Jun 1970

6. Andrith and Ogg, The Chemistry of Hydrazine, John Wiley & Sons, New York, 1951

7. B. M. Greenough and T. M. Olcott, "A Spacecraft Electrolytic Oxygen-Nitrogen Generation System," presented at the Space Technology and Heat Transfer Conference, ASME, Jun 1970

LIBRARY CARD ABSTRACT

Research was conducted in the development of a noncryogenic technique of hydrazine/water electrolysis for generating oxygen and nitrogen for use in long-duration manned space missions. A breadboard one-man model O_2/N_2 generation system was integrated with a cabin and metabolic/leak simulator. Automatic control of the cabin total pressure and cabin oxygen partial pressure was demonstrated for various metabolic loads with a fixed cabin leakage. A total of four one-week tests were run. Experimental electrodes were tested in the system in addition to some 5,000 hr of cumulative single-cell tests. A computer routine model of the O_2/N_2 generation system was revised and verified with experimental test data. A preliminary design and specification of a full-scale 12-man O_2/N_2 system was completed yielding a system capable of handling up to 33.7 lb/day cabin leakage and a 12-man metabolic load. Total system weight, including spares, is 862 lb. The system requires a maximum of 7,830 watts under nominal conditions and has redundancy and spares for a reliability of 0.9980 for a 180-day mission.

Appendix A
ONE-MAN MODEL SYSTEM CIRCUIT DIAGRAMS

Circuit diagrams of the control logic, power conditioning, and voltage/current monitors used in the one-man model O_2/N_2 system are presented in this Appendix.

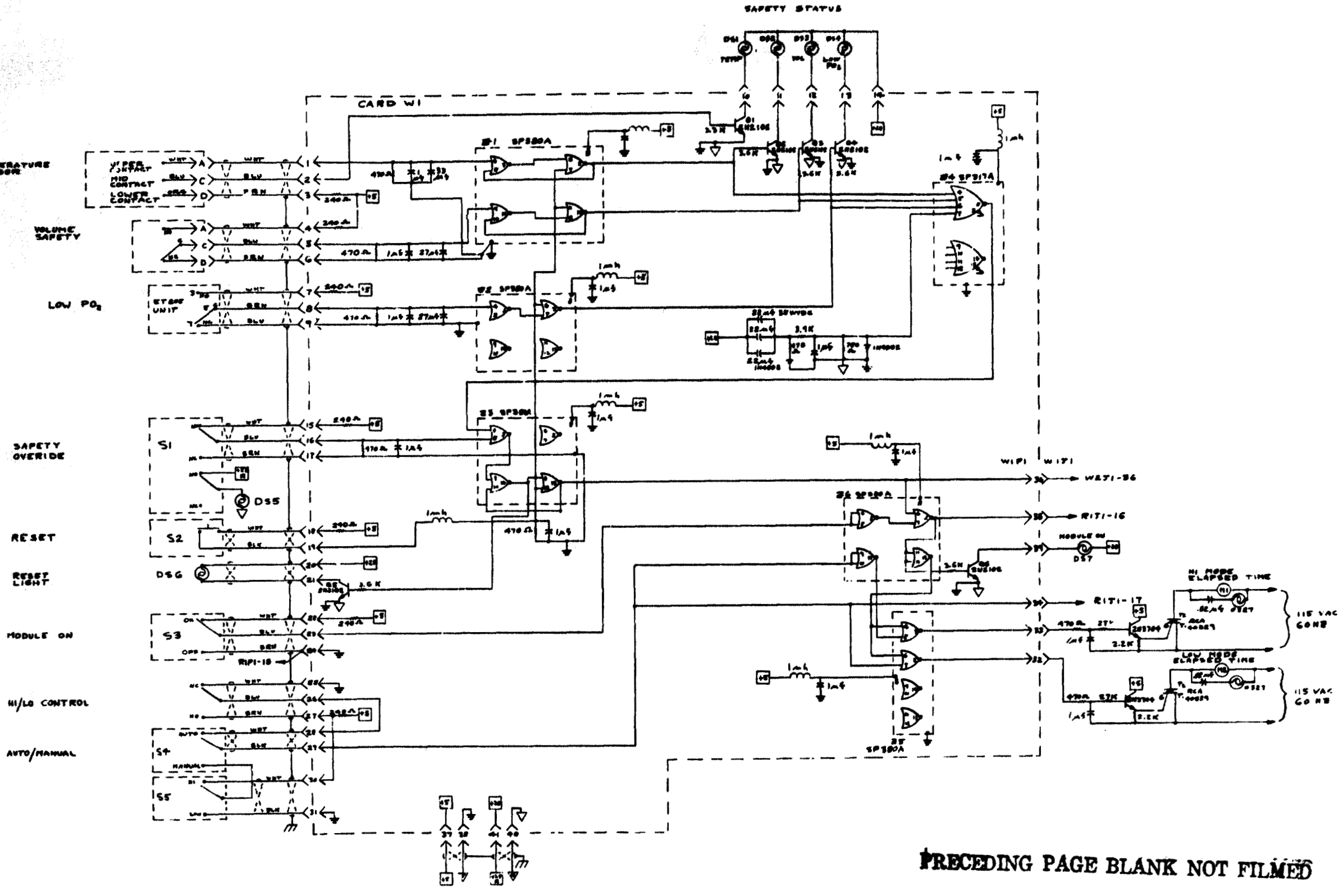

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Fig. A-1 Control Logic Card 1

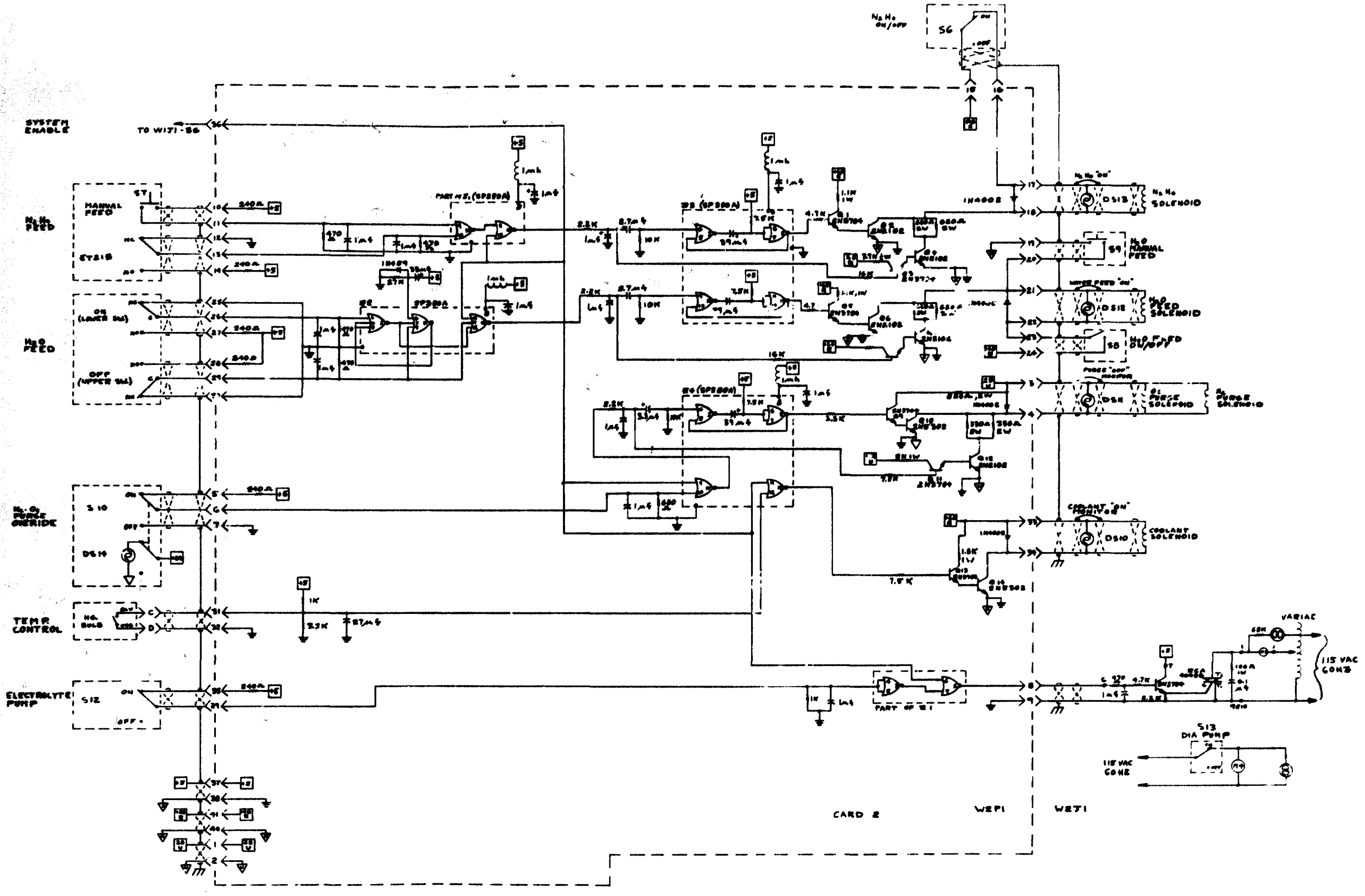

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Fig. A-2 Control Logic Card 2

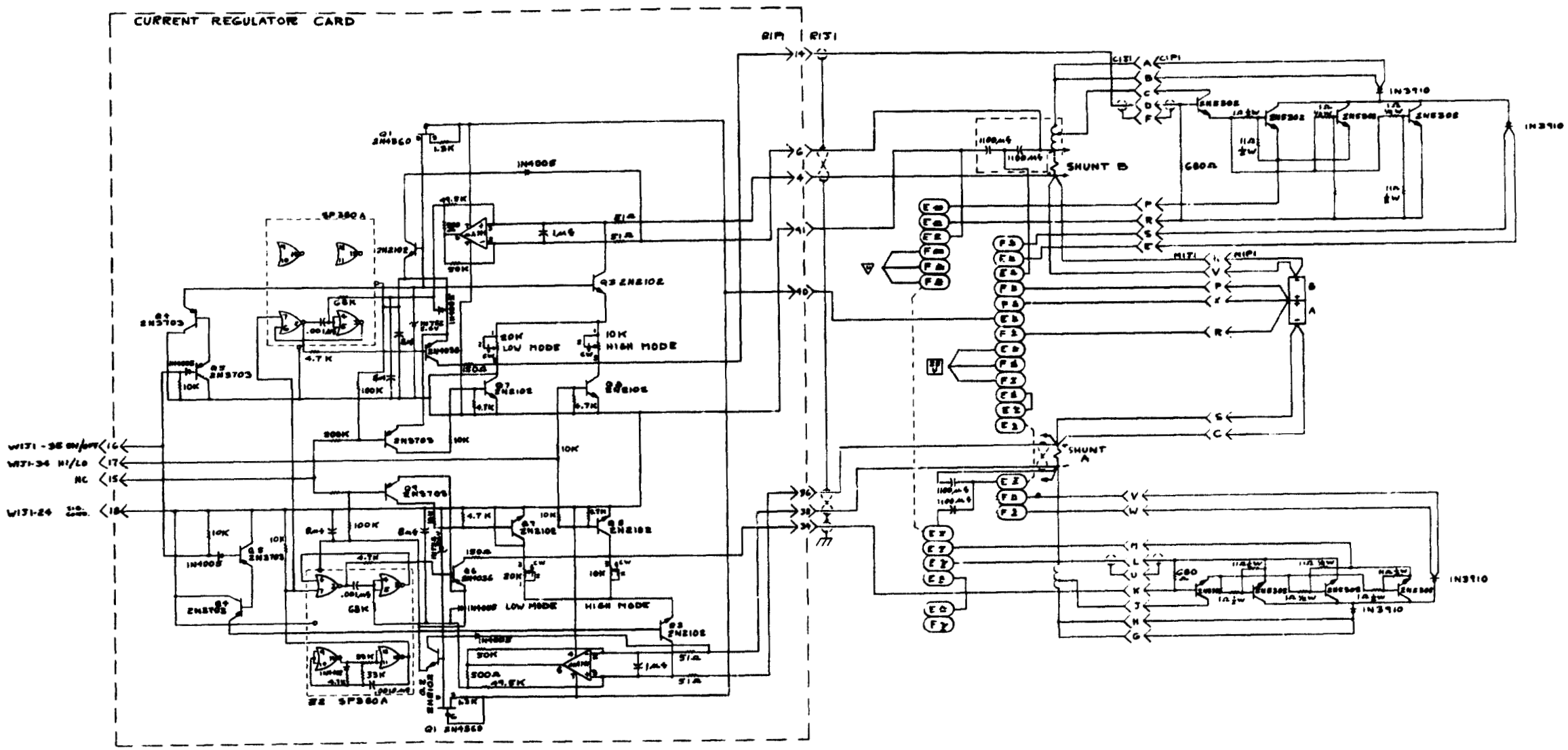

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Fig. A-3 Current Regulator

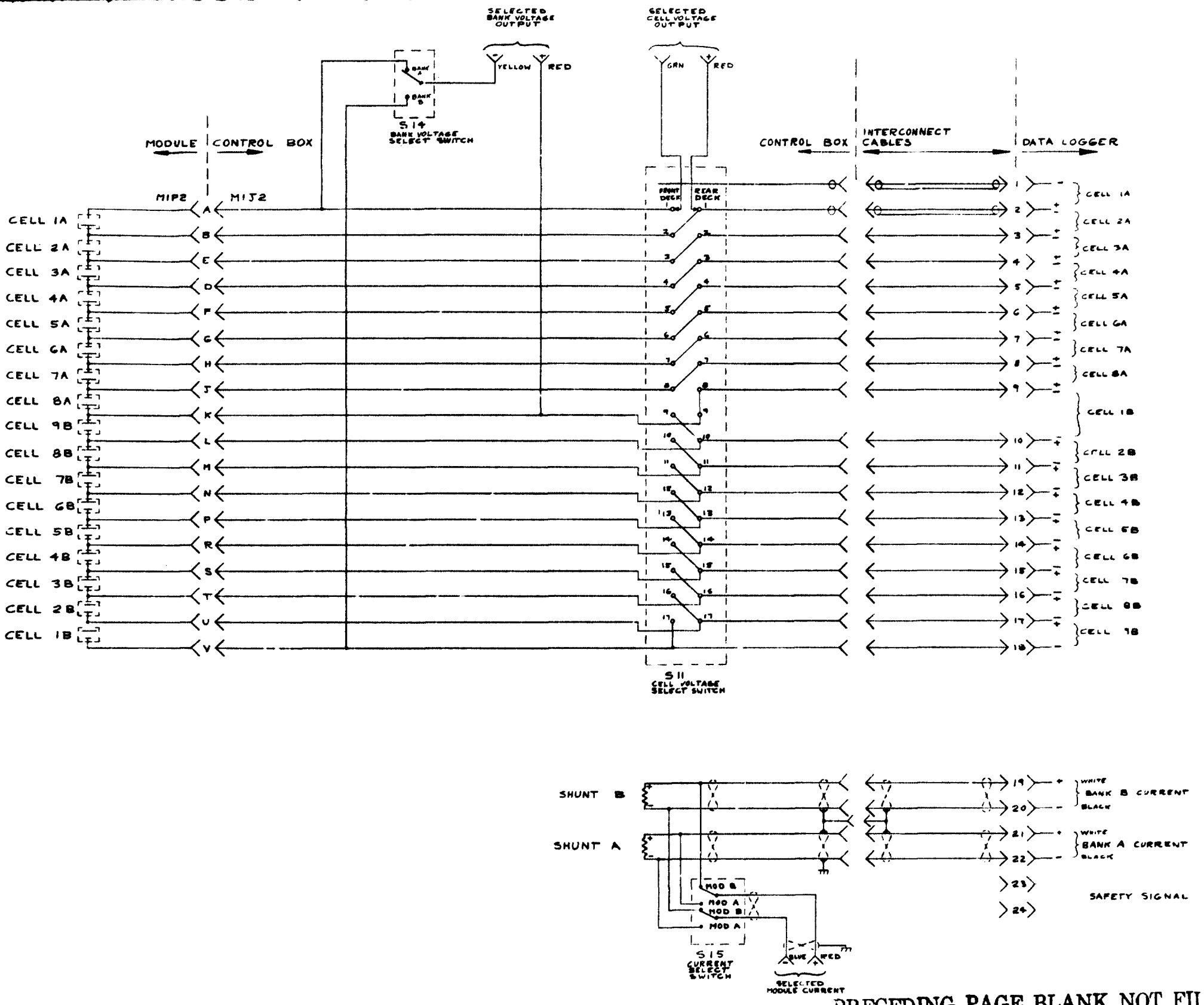

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Fig. A-4 Voltage/Current Monitor

Appendix B

OPERATION INSTRUCTIONS FOR THE ONE-MAN MODEL O_2/N_2 SYSTEM

A. Manual Shutdown

1. Emergency shutdown: Disconnect labelled power supply cords behind monitoring consoles.
2. Normal shutdown:
   a. Turn off N_2H_4 feed switch.
   b. Turn off H_2O feed switch.
   c. Turn on N_2 purge switch.
   d. Switch to manual, low current mode on electrolysis module control panel.
   e. Turn off module power switch.
   f. Turn off dia-pump switch.
   g. Turn off KOH pump switch.
   h. Turn off power supplies in this order:
      (1) 28 Vdc (PS 3)
      (2) 28 Vdc (PS 2)
      (3) 5 Vdc (PS 1)
   i. Press POWER OFF button.
   j. Pin reservoir.
   k. Check N_2 purge flow rate and adjust.

B. Manual Start-up

1. Switch positions:
   a. Module power – off
   b. Module mode – manual, low
   c. Safety override – on
   d. N_2H_4 feed – off
   e. N_2O feed – off
   f. N_2 purge – on
   g. KOH pump – off
   h. Dia-pump – off

2. Press POWER ON button.
3. Turn on power supplies in this order:
   a. 5 Vdc (PS 1)
   b. 28 Vdc (PS 2)
   c. 28 Vdc (PS 3)
4. Press RESET button.
5. Turn on KOH pump switch: Adjust variac to 70 or flow of 5 units on flowmeter C. Check to see that bubble separator gas line is not drawing in H_2O; adjust flow downward with flow control value if there is suction pressure or bubble separator.
6. Turn on H_2O feed switch.
7. Turn on module power switch; check that low currents (modules A and B) read ~11.2 mV.
8. Switch to manual high current; check that currents (modules A and B) read ~33.8 mV.
9. Turn on dia-pump switch. When P_{Total} reaches 12.3 psia (~61.5 on recorder), do the following:
   a. Switch to automatic current.
   b. Turn off N_2 purge.
   c. Turn off safety override.
   d. Set metabolic leak to _____ cc/min. (_____SS).
   e. Set N_2 makeup to _____ cc/min. (_____SS).
   f. Turn on N_2H_4 feed to _____ cc/min. (_____SS).
   g. Set pressure regulator to 1 psig.

C. Start-up From Automatic Shutdown
1. Switch positions:
   a. Module power – off
   b. Module mode – manual, low
   c. Safety override – on
   d. N_2H_4 feed – off
   e H_2O feed – off
   f. N_2 purge – on

g. KOH pump – off, variac 0

h. Dia-pump – off

2. Press RESET button.

3. Turn on KOH pump switch; adjust flow with variac (~70 V).

4. Turn on H_2O feed switch.

5. Turn on module power switch; check low currents (~11.2 mV), then check high currents (~33.8 mV).

6. Turn on dia-pump; adjust metabolic leak and N_2 makeup.

7. Turn off N_2 purge switch.

8. Turn on N_2H_4 feed.

D. Calibration

1. F3 O_2 Analyzer

a. Open cal vent valve.

b. Set cal vent 3-way valve in vent position.

c. Set cal loop 3-way valve in cal position.

d. Set O_2/N_2 3-way valve in N_2 position.

e. Adjust flow through cal loop flowmeter to ~50 cc/min.

f. Allow ~10 to 15 minutes for purging of F3; then adjust F3 zero knob to read 0 percent.

g. Set O_2/N_2 3-way valve in O_2 position.

h. Allow ~10 to 15 minutes for purging of F3; then adjust F3 span knob to read 100 percent.

i. Return 3-way valves to normal cal loop positions:

(1) Cal loop 3-way valve in loop position

(2) Cal vent 3-way valve in loop position

(3) O_2/N_2 3-way valve in N_2 position

2. PO_2 Control Sensor and Data Sensor

a. Turn off N_2H_4 feed switch.

b. Turn on sensor bypass valve and turn off sensor loop valves.

c. Disconnect sensor cables and remove sensors from canister, then reconnect sensor cables.

d. Turn control amplifier to zero position and adjust zero reading; turn to 250 mm position and set calibration to give meter reading of 118 mm. Repeat same procedure for data sensor; also check that PO_2 recorder reads correctly (the zero can be adjusted on the recorder).

e. Replace sensors in canister; turn on sensor valves and turn off bypass valve.

f. Turn on N_2H_4 feed switch.

g. If sensor is reading above 154 mm, note reading and turn calibration knob below 154 mm, then back to reading noted.

3. PO_2 Safety sensor

a. Turn on safety override switch.

b. Turn on sensor bypass valve and turn off sensor loop valves.

c. Remove sensor from canister.

d. Turn amplifier to zero position and adjust zero reading; turn to 1,000-mm scale and set reading with calibration knob to 160 mm.

e. Replace sensor in canister; turn on sensor loop valves and close bypass valve.

f. Turn off safety override switch.

E. Current Adjustment

1. Adjust low current as follows:

a. Switch on manual low current.

b. Connect voltmeter to module current readout.

c. Put module current-selector switch on "A" and adjust "low A" potentiometer on Electronics Card 1 to read ~11.2 mV.

d. Switch to "B" and adjust "low B" potentiometer on Card 1 to read ~11.2 mV.

2. Adjust high current as follows:

a. Switch to high current on the electrolysis module.

b. Turn current-selector switch to "A" and adjust "A high" potentiometer on Electronics Card 1 to ~33.8 mV.

c. Switch to "B" and repeat.

F. Filling H_2O and N_2H_4 Tanks

1. Fill H_2C tank as follows:
   a. Turn off H_2O feed switch.
   b. Close off tank pressurization valve tc isolate H_2O tank from N_2 supply.
   c. Open H_2O vent valve to depressurize H_2O tank.
   d. Drain H_2O tank through H_2O fill line and measure volume of H_2O.
   e. Connect H_2O fill bottle to H_2O fill line.
   f. Open H_2O fill valve.
   g. Pump in measured amount of distilled H_2O.
   h. Close H_2O fill valve.
   i. Close H_2O vent valve.
   j. Open tank pressurization valve to pressurize H_2O tank.
   k. Turn on H_2O feed switch.
2. Fill N_2H_4 tank as follows:
   a. Turn off N_2H_4 feed switch.
   b. Open N_2H_4 vent valve to depressurize N_2H_4 tank. Keep N_2 purge flowing over N_2H_4 tank.
   c. Drain N_2H_4 from N_2H_4 tank through N_2H_4 fill line, and measure volume.
   d. Connect N_2H_4 fill bottle to N_2H_4 fill line.
   e. Open N_2H_4 fill valve.
   f. Pump in measured volume of N_2H_4, but <u>do not pump in air</u>. Measure remaining N_2H_4 in fill bottle to determine amount of N_2H_4 introduced into tank.
   g. Close N_2H_4 fill valve.
   h. Close vent valve to pressurize N_2H_4 tank.
   i. Turn on N_2H_4 feed switch.

Appendix C

BREADBOARD SYSTEM TEST DATA LOGS

TEST NO. 1 — SYSTEM STATUS — PAGE 1 OF —

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	POWER INPUT HIGH AMPS	POWER INPUT LOW VOLTS	POWER INPUT LOW AMPS	PRESSURE (PSIG) MUD[1]	PI[2]	PO_2[3]	LAL[4]	NH_3[5]	COOLANT TEMP (°F)	FLOW RATE KOH	FLOW RATE QUANT	FLOW RATE NH_3	FLOW RATE META	FLOW RATE N_2	KNB °EP	GAS ANALYSIS N_2-O_2	GAS ANALYSIS CAB.N	GAS ANALYSIS H_2
								in H2O	in Hg	mm Hg	psia	psia		limits	ml/min	cc/min	cc/min	cc/min	VOLTS			
9-22	4:15	0	2182.2			28.5	6.8	40	5.0	135	2.2	6.1	59	6.0	.5	.575	2040	1680	—			
	5:00	~1	1483.1			28.5	6.0	39	4.0	137	2.2	6.1	57	6.5		.575	>3500	>2000	—	80% O_2 20% N_2 (6:00)		
	8:05	4	1495.2			28.5	21.5	34	5.0	150	2.0	6.0	49	5.4	.5	.575	>3500	>2000	37cc	67% O_2 33% N_2 (9:45)		
	11:40	7:35	1509.6			28.6	5.5	23	3.1	166	2.1	6.0	53	3.8	—	.035	2440	1290	60cc	60% O_2 40% N_2 (11:45)		
9-23	12:40	8:35	1511.5			28.5	5.8	26	4.2	170	2.1	6.0	50	5.3	—	.057	[illegible]	1300	120cc			
	10:31	9:30		28.6	21.2			27	4.2	187	2.1	5.8	50	5.0		.043	2180	1280	23 cc	33		
	12:37	10:30	1518.3	28.6	22.5			25	4.2	213	2.1	5.9	50	4.3	5	.057	2250	1280	64 cc	31		
	3:35	11:30	1521.8	28.7	23.0			23	4.2	233	2.1	5.9	49	5.0	5	.043	2180	1280	90 cc	26		
	4:30	12	1525.1	28.8	22.0			36	4.2	253	2.1	5.9	50	5.0	5	.055	2180	1280	32 cc			
	5:30	13	1529.0	28.7	23.0	28.6	5.8	33	4.2	273	2.1	5.8	50	5.2	0	.00	2180	1280	30 cc			
	6:30	14	1532.5	28.7	23.6			31	4.1	289	2.1	5.8	49	5.0	5	.043	2180	1280	18 cc			
	10:45	18.2	1546.5	28.7	25			52	4.1	46%	2.1	5.9	49	4.9		0	2180	1339	69			
	12:45	20.2	1554.5	28.5	19			42	4.6	31%	2.1	5.9	49	5.0	5	1.44	flow on	flow on	@ 100	42 cc/min @ 11:00 a.m 9-23		
	2:45	22.2	1564.0	28.5	19.5			33	5.5	170	2.1	5.9	48	4.5	6	-0-	[illegible]	[illegible]	90	42% O_2 (2:30)		
	4:45	24.2	1574.1	28.5	19.5			31.5	4.2	151	2.1	5.9	47	3.7	5	.85	2180	1280	[illegible]			
	6:45	26.2	1584.1	28.5	6.0	28.5	6.0	33.5	4.2	152	2.1	5.9	50	4.2	0	.65	2180	1700	125 cc			
	8:45	28.2	1588.1	28.5	5.9	28.5	5.9	32.0	4.0	137	2.1	5.9	52	4.0	0	—	2180	1700	140	46% O_2 (9:30pm) 69% N_2 14% O_2 17% N_2 @ 11:45pm		
	10:45	30.2	1586.1			28.5	5.9	35.5	4.0	126	2.1	5.8	54	4.0	0	—	2180	1700	160			
9-24	12:35	32	1588.3			28.5	5.7	27	4.0	126	2.1	5.9	54	4.0	0	—	2180	1700	130			
	2:35	34	1591.0			28.5	5.9	30	4.0	127	2.1	5.9	56	4.0	0	0	2180	1700	140			
	4:35	36	1593.4			28.6	5.4	33.5	4.0	130	2.1	5.95	58	4.0	0	0	2180	1700	145	note exhaust gas cycle		
	6:35	38	1595.5			28.6	5.7	36.0	4.0	—	2.1	6.0	55	4.0	0	0	2180	1700	155			
	10:45 a.m	42.2	SEE LOG NOTES																			
	10:50		1601.7			28.6	5.7	33	4.1	161	2.1	5.9	52	4.0	—	15 cc/min	2180	1700	155			
	12:25	44	Changed unit. to 4:1 scale reading and N_2 to 16 scale reading																			
	1:30	45	1609.5	28.5	20.0	28.5	5.7	34	4.0	157	2.1	5.9	49	3.8	.5	.072	4:1 scale 2180	16 scale 12.5 scale	250			
	3:40	47.2	1626.5	28.5	19.9			31	4.1	149	2.1	5.9	48	3.8	.6	.72	4:1 scale 2180	16 scale 12.5 scale	270			
	3.45		N_2H_4 feed went off - adjusted unit & N_2																			
	4:45	49.2	N_2 adjusted back to 13.6																			
	5:25	49	N_2 adjusted back to 12.5																			

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* increase N_2H_4 to 11.0 ss at 7:53 PM

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	POWER INPUT HIGH AMPS	POWER INPUT LOW VOLTS	POWER INPUT LOW AMPS	PRESSURE (PSIG) MOD	PT	PO_2	CAL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	FLOW RATE COOLANT	FLOW RATE N_2H_4	FLOW RATE META	FLOW RATE N_2	FLOW RATE AIR	GAS ANALYSIS N_2-O	GAS ANALYSIS CABIN	GAS ANALYSIS H_2
9.24	5:45		1624.1	28.5	20.5			29.5	4.1	163	2.1	5.9	45°	3.6	1.0	9? scale	2180	12.5 scale	296			
	7:55	51.5	1632.2	~~28.5~~	&	28.5	5.5	29.5	4.1	178	2.1	5.9	44	4.1	0	11.0 scale *	2180	12.5 scale	315			
	9:30	53	changed calibration on P_{O_2} sensors (.01 from 174 to 155 mm to correct for 2 psia pressure in cabin																			
	9:45		1640.5	28.5	20.5			33	4.1	155	2.1	5.9	41	3.5	.6	7.2 ss	2180	12.5 scale	350			
	11:46		1648.1	28.5	21.9			31.5	4.1	143	2.1	5.9	41	4.0	1.0	—	2.0 ss scale	1.0 ss scale	360			
	12:10	Reset to correct control condition (note: N_2, N_2H_4 feed)																				
9.25	12:35	56	1651.8	28.7	21.0	28.6	5.7	38	4.1	152	2.1	5.8	44	4.5	.8	4.6 ss	2180	12.5	360			
	2:35	58	1658.5	28.7	20.9	28.6	5.7	39	4.1	153	2.1	5.9	44	4.2	.8	5.0 ss	2180	12.5	370			
	4:35	60	1665.75	28.7	23			25	4.1	166	2.1	5.9	43	4.3	.8	5.5 ss	2180	12.5	380			
	6:35	62	1673.4	28.7	21.9			26	4.1	167	2.1	5.9	42	4.2	.8	5.0	2180	12.45	390			
	8:00	Adjust N_2H_4 feed upward to ~7.2 ss but put it back down to 5.2 ss																				
	8:44	Lowered chiller temp. by 4°F (~38°F)																				
	9:35	65	1684.2	28.6	21.2	28.5	5.6	35	4.1	164	2.1	5.9	42	3.8	.8	5.2 ss	2180	12.5	~~425~~	(Refilled H_2O tank)		
	10:00	coolant cycle off																	440			
	12:37	68	1695.5	28.6	22.5			31	4.1	163	2.1	5.9	42	4.0	.8	5.2 ss	2180	12.5	~~460~~	N_2 makeup @ ~12.4, readjusted to 12.5 ss		
	3:05	70.5	1704.5	29.5	22.6			30	4.2	160	2.1	5.9	42	4.2	.8	5.5 ss	2180	12.5	460			
	6:00	73.5	1715.0	~~28.5~~	21.0			35	4.2	158	2.1	5.9	44	3.6	.8	5.5 ss	2180	12.5	450			
	7:47	75.2	1721.2	~~28.5~~		28.5	5.8	41	4.2	158	2.1	5.9	44	3.9	.8	4.7 ss	2180	12.4	455			
	10:15	77.8	Recalibrate PO_4 sensors (control) N_2H_4 to 6.2 ss at 10:48 PM																			
		76.8	11:15 turn H_2O feed off, system OK, flow ~550 @ 1:18 1:23 US 17 @ start																			
9.26	1:35	81	1740.6			28.6	5.7	37	4.4	146	2.1	5.95	48	4.8	0	0	2.0	7.0	20	[KOH] = 3M (1:15 AM)		
	2:30		1742.2			28.7	5.9	34	4.2	146	2.1	~~5.9~~	52	5.0	.8	0 off	2.0	6.0	42			
	4:30		1744.9			28.8	5.8	24	4.2	208	2.1	5.9	54	4.8	.8	off	2.3	7.5	73	add 60cc KOH @ 4:42		
	6:30		1747.5			28.5	5.6	35	4.2	158	2.1	5.9	56	4.8	—	off	2.6	8.5	102	add 69cc KOH @ 6:00		

TEST NO. 1

MODULE STATUS

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DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	[illegible] PO_2	N_2H_4 CONC. *
9-22	4:30	9.59	7.43	LO 5	13.8	14.98	4.3	4.4	1.671	1.765	1.821	1.629	1.805	1.763	1.748	1.600	1.704	1.642	1.623	1.693	1.648	1.661	1.665	1.665	1.677	31% (?)	
	5:30	NOT WORKING	8.06	HI 1.5	16.0	17.45	13.6	13.6	2.033	2.213	2.105	1.813	1.995	2.008	2.061	1.772	1.975	1.824	1.822	1.960	1.864	1.913	2.010	2.003	2.077	33%	.06 M (6:00 AM)
	7:30	11.36	8.06	HI 3.5	15.79	17.54	13.6	13.5	2.165	2.269	2.134	1.789	1.820	1.830	2.027	1.753	1.932	1.784	1.790	1.908	1.837	1.900	2.096	2.121	2.193		1.31 (8:00 AM)
	8:30	12.40	8.06	HI 4.5	15.96	17.72	14.0	13.8	2.228	2.308	2.160	1.803	1.840	1.832	2.035	1.759	1.923	1.779	1.783	1.908	1.840	1.908	2.144	2.194	2.241	29%	
	9:45	13.64	8.06	HI	15.81	17.59	13.4	13.5	2.215	2.281	2.145	1.795	1.820	1.807	1.997	1.748	1.906	1.761	1.769	1.894	1.829	1.893	2.153	2.182	2.220	23%	1.27 (10:00 AM)
	11:40	14.92	8.67	LO 7.5	11.17	11.16	13.44	14.98	1.71	1.80	1.70	1.62	1.66	1.64	1.73	1.60	1.62	1.61	1.60	1.69	1.64	1.66	1.68	1.69	1.73	23%	1.25 (11:00 AM)
9-23	12:15	— leak on PO_2 safety fitting ⇒ high system pressure — increased [illegible] to 8.06 [illegible]																									
	12:25	— Reset Qmet to 4																									
	12:32	15.01	9.48	LO 9.5	11.27	11.25	13.47	15.03	1.72	1.82	1.70	1.62	1.66	1.64	1.73	1.60	~~1.98~~	~~1.82~~	~~1.82~~								
	~~[illegible]~~			HI	34.38	34.20	15.82	17.49	2.06	2.24	1.97	1.86	1.89	1.88	2.10	1.82	2.00	1.83	1.82	1.97	1.88	1.92	1.97	1.98	2.05	52%	
	1:22	15.55	9.76	HI 9.5	15.91	17.56	33.6	33.6	2.12	2.28	2.06	1.84	1.89	1.87	2.10	1.81	2.00	1.82	1.81	1.98	1.87	1.92	2.05	2.01	2.18	50%	
	2:30	16.49	9.86	HI 10.5	16.48	18.2	35.36	34.8	2.31	2.39	2.23	1.85	1.87	1.87	2.13	1.81	2.02	1.82	1.82	2.02	~~1.85~~	1.93	2.11	2.04	2.18	48%	
	"			LO	13.82	15.24	10.9	11.0	1.86	1.91	1.90	1.61	1.66	1.64	1.73	1.59	1.68	1.62	1.60	1.70	1.66	1.69	1.81	1.77	1.87	35%	
	3:30	17.33	10.03	LO 11.5	12.86	15.23	10.95	10.95	1.80	1.89	1.91	1.61	1.66	1.64	1.73	1.60	1.69	1.62	1.61								
	"			HI	16.45	18.68	35.24	34.97	2.35	2.23	1.85	1.91	1.89	2.13	1.82	2.03	1.82	1.83	2.04	1.98	1.84	1.92	2.13	2.01	2.15	48%	
	4:20	in air composition sensor (feed gas) 17% full limit of cal																									
	4:25	, O_2 Data reached 250 mm Hg — switched to 1000 mm scale cyclic — get data from E3																									
	4:30	18.18	10.15	HI 13.6	14.1		35.6	35.2																			
				LO	14.1	15.5	10.96	10.97	1.86	1.91	1.82	1.62	1.66	1.65	1.73	1.60	1.69	1.62	1.61	1.71	1.65	1.78	1.78	1.79	1.82	36%	
	5:30	18.60	10.31	HI 13.5	16.7	18.5	36.0	35.3	2.36	2.44	2.23	1.86	1.91	1.90	2.16	1.82	2.05	1.83	1.83	2.05	1.88	1.93	2.23	2.30	2.34	45%	
	6:30	19.14	10.51	HI 14.5	16.7	18.4	36.3	35.2	2.33	2.45	2.24	1.87	1.92	1.90	2.17	1.83	2.05	1.83	1.84	2.06	1.89	1.95	2.24	2.29	2.31	45%	
	7:00	low mode effluent (.325) High mode (.44)																									
	10:30	hydrazine feed has been incorrect — turned off to put in new flowmeter; N_2H_4 conc. analysis indicates ~0 M (i.e. no N_2H_4 in electrolyte at this point)																									-0-
	10:35	21.88	10.92	HI 19.5	16.95	18.9	14.2	13.9	2.333	2.466	2.248	1.874	2.025	1.969	2.182	1.840	2.081	1.840	1.84	2.086	1.905	1.935	2.219	2.297	2.304	44%	
	11:30	22.56	11.10	HI 19.5	16.51	18.18	13.6	13.6	2.280	2.427	2.211	1.845	1.948	1.871	2.121	1.811	2.020	1.816	1.826	2.042	1.865	1.912	2.171	2.251	2.265		
	12:30	23.56	11.10	HI 19.5	15.73	17.3	13.0	13.2	2.198	2.351	2.116	1.774	1.796	1.785	1.965	1.734	1.879	1.748	1.748	1.863	1.791	1.853	2.051	2.152	2.188	42%	
	1:00	—																								→	2.53 M (KOH NOT REPLACED)
		turned N_2H_4 feed off manually at 1:30 p.m																									
	1:30	24.52	11.10	HI 21.5	15.01	16.58	13.0	13.1	2.115	2.306	1.994	1.732	1.740	1.719	1.795	1.681	1.751	1.687	1.682	1.775	1.748	1.829	1.958	2.007	[illegible]	29%	
	2:30	25.52	11.10	HI 22.5	15.31	16.92	13.0	13.1	2.197	2.345	1.915	1.766	1.787	1.758	1.837	1.728	1.814	1.731	1.730	1.824	1.792	1.861	1.991	2.[illegible]		43%	
	3:00	turned N_2H_4 on — back on auto mode																									1.87 M (KOH NOT REPLACED)

* [illegible] 4 [illegible]

TEST NO. 1 — MODULE STATUS — PAGE 2 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	1B	2B	3B	4B	5B	6B	7B	8B	ELECTROLYTE POT.	NaHA CELL *	
9-23	3:37	26.40	11.10	24.5 HI	15.31	16.84	13.0	13.2	2.198	2.319	1.907	1.764	1.781	1.764	1.841	1.725	1.818	1.721	1.719	1.819	1.781	1.850	1.972	2.005	2.153	40 %		new sub assy effective here 3:30
	4:31	27.53	11.10	24.5 HI	15.29	16.88	13.0	13.1	2.226	2.341	1.909	1.762	1.781	1.758	1.835	1.721	1.804	1.728	1.723	1.824	1.797	1.864	1.995	2.026	2.182	43%		
	5:30	28.14	11.36	25.5 LO	3.34	14.93	4.5	4.5	1.712	1.830	1.696	1.605	1.644	1.615	1.647	1.586	1.637	1.601	1.577	1.676	1.63	1.668	1.688	1.709	1.735	27%		
	6:30	28.14	12.26	26.5 LO	13.44	14.94	4.5	4.5	1.696	1.835	1.705	1.619	1.654	1.628	1.672	1.605	1.658	1.618	1.585	1.679	1.638	1.666	1.671	1.683	1.705	29%		
	6:32	28.14	13.27	27.5 LO	3.46	14.94	4.5	4.5	1.694	1.840	1.708	1.624	1.661	1.634	1.678	1.611	1.663	1.622	1.588	1.681	1.643	1.667	1.670	1.682	1.703	32%	1.5M (?)	
	8:31	28.14	14.20	28.5 LO	13.48	14.95	4.5	4.5	1.699	1.848	1.709	1.627	1.667	1.638	1.684	1.617	1.670	1.626	1.583	1.683	1.641	1.669	1.671	1.683	1.688	34%		
	9:31	28.14	15.26	29.5 LO	13.51	14.97	4.5	4.5	1.703	1.849	1.707	1.632	1.674	1.647	1.694	1.622	1.678	1.631	1.600	1.687	1.650	1.675	1.679	1.692	1.699	38%		
	10:33	28.14	16.30	30.5 LO	13.57	15.02	4.5	4.5	1.692	1.851	1.709	1.641	1.683	1.655	1.704	1.630	1.691	1.643	1.608	1.693	1.653	1.673	1.669	1.678	1.681	44.5	.48M (110)	
	11:32	28.14	17.27	31.5 LO	13.58	15.02	4.5	4.5	1.691	1.851	1.708	1.642	1.688	1.659	1.711	1.634	1.694	1.644	1.609	1.695	1.654	1.673	1.668	1.675	1.688	46%		
9-24	12:30	28.14	18.24	32.5 LO	13.59	15.02	4.5	4.5	1.69	1.85	1.708	1.643	1.689	1.661	1.713	1.632	1.698	1.647	1.612	1.697	1.657	1.673	1.667	1.674	1.683	48%		
	1:30	28.14	19.25	33.5 LO	13.61	15.03	4.5	4.5	1.693	1.851	1.708	1.647	1.691	1.663	1.717	1.639	1.702	1.649	1.614	1.697	1.657	1.674	1.669	1.676	1.691	49%		
	2:30	28.14	20.23	34.5 LO	13.61	15.03	4.4	4.5	1.688	1.852	1.707	1.645	1.693	1.666	1.717	1.640	1.702	1.650	1.614	1.700	1.660	1.674	1.668	1.676	1.688	50%		
	3:30	28.14	21.23	35.5 LO	13.58	14.99	4.4	4.45	1.677	1.837	1.704	1.644	1.683	1.665	1.717	1.639	1.702	1.649	1.613	1.698	1.651	1.669	1.661	1.667	1.680	51%		
	4:30	28.14	22.24	36.5 LO	13.62	15.02	4.4	4.4	1.684	1.852	1.712	1.647	1.697	1.668	1.719	1.641	1.703	1.652	1.615	1.701	1.659	1.672	1.663	1.671	1.682	.51%		
	5:30			Cal	Sensors		O_2		Data		O.K		148 in room		Set to		160											
									Control				148 in room		set to		160											
	5:37	28.14	23.36	LO 37.5	13.63	15.05	4.4	4.45	1.688	1.857	1.715	1.647	1.694	1.668	1.718	1.642	1.706	1.654	1.617	1.703	1.661	1.676	1.671	1.676	1.686	51%		
	6:20			Shut clock on F3			5.5	shut	.08	00	set to	0		spm 24.7		set to 25												
	6:30	28.14	24.31	LO 38.5	13.63	15.05	4.4	4.45	1.687	1.856	1.717	1.645	1.700	1.670	1.718	1.641	1.705	1.655	1.618	1.705	1.662	1.674	1.671	1.677	1.685	51%		
	7:15	F3 cal completed back on tank loop.																										
	7:30	Turned off N_2 purge manual valve to check if N_2 purge solenoid leaking - OK back on																										
	10:45	SEE	LOG	NOTES																								
	11:00	28.71	29.91	LO 43.5	15.83	17.32	12.4	12.7	1.977	2.326	2.014	1.866	1.922	1.886	2.007	1.849	1.986	1.859	1.837	1.974	1.895	1.911	1.944	1.955	1.988	71%		
	11:15																										0.9M	KOH NOT REPLACED
	12:55	29.65	29.10	HI 45	15.60	17.34	13.2	13.3	2.073	2.366	1.976	1.936	1.854	1.822	1.906	1.795	1.902	1.813	1.799	1.932	1.874	1.927	1.999	2.038	2.105	53%	1.92 M	
PM	2:30	29.95	29.52	HI 46.5	15.67	17.40	13.2	13.3	2.102	2.384	1.964	1.832	1.846	1.828	1.913	1.797	1.889	1.863	1.789	1.932	1.868	1.927	2.014	2.054	2.128			
	3:38	30.48	30.02	LO 47.5	13.13	14.67	4.5	4.5	1.738	1.848	1.693	1.584	1.603	1.519	1.604	1.558	1.571	1.564	1.412	1.656	1.664	1.659	1.697	1.732	1.763			
	4:35	31.20	30.15	HI 48.5	15.45	17.18	12.0	12.9	2.139	2.375	1.952	1.810	1.831	1.805	1.881	1.772	1.886	1.784	1.780	1.921	1.834	1.913	2.005	2.060	2.154	54%		
	5:15			HI			13.5	13.5	→ adjusted current up in hi mode																			
	5:30	31.80	30.46	HI 49.5	15.97	17.64	13.5	13.5	2.240	2.422	2.000	1.847	1.871	1.836	1.925	1.804	1.909	1.807	1.806	1.949	1.883	1.947	2.057	2.134	2.238			
	6:31	32.56	30.60	LO 50.5	13.22	14.75	4.4	4.4	1.764	1.863	1.693	1.574	1.607	1.575	1.615	1.561	1.586	1.568	1.484	1.656	1.617	1.665				54 %		
	6:35			HI																			2.021	2.082	2.135	40%		

* EVERY 4 HOURS

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TEST NO. 1 — MODULE STATUS — PAGE 3

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	1B	2B	3B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	% FULL	N_H4 ★
9-24	7:31	33.10	30.77	Lo 51.5	15.68	14.8																					
				Hi			13.3	13.4	2.258	2461	2024	1841	1850	1832	1.927	1807	1.902	1813	1.798	1.947	1.877	1.964	2068	2123	2222	54%	1.83M (7:25)
	8:31	33.68	30.95	Hi 52.5	15.87	17.56	13.8	13.4	2.337	2466	1.992	1.802	1.812	1.801	1.865	1.767	1.876	1.772	1.774	1.907	1.856	1.927	2.051	2.130	2.237	41%	2.53M (8:44)
	9:38	34.49	31.21	Hi 54.5	15.94	17.54	13.6	13.6	2.378	2.442	1.968	1.792	1.900	1.819	1.921	1.768	1.895	1.762	1.763	1.582	1.476	1.509	1.702	1.742	1.772	32%	2.34M (10:20) just before [illegible]
	10:42	35.23	31.52	Hi 55.5	16.15	17.67	13.5	13.5	2.349	2444	1.979	1.804	1.981	1.894	1.949	1.784	1.951	1.763	1.769	1.899	1.845	1.925	2.059	2.161	2.275	47%	
	11:30	35.51	31.60	Hi 55.5	16.62	18.11	14.1	13.8	2446	2505	2025	1.840	2068	1.999	2025	1.820	2023	1.804	1.812	1.930	1.870	1.963	2.130	2.260	2.380	57%	
9-25	12:30	35.90	31.90	Hi 56.5	16.57	17.94	13.0	13.1	2.324	2.460	2.031	1.841	2.095	2.017	2.021	1.921	2.070	1.914	1.921	1.943	1.976	1.948	2.102	2.208	2.334	61%	
				Lo	13.72	15.01	3.6	3.4	1.760	1.935	1.717	1.601	1.900	1.684	1.683	1.591	1.695	1.592	1.582	1.669	1.634	1.641	1.702	1.727	—		
	1:30	36.47	32.13	Lo 57.5	13.80	15.06	4.3	4.35												1.[illegible]	1.672	1.632	1.704	1.732	1.753		
	1:30			Hi	16.66	17.87	13.3	13.35	2.200	2461	2.058	1.850	2.124	2.039	2.034	1.828	2.074	1.823	1.523	1.557	1.889	1.942	2.045	2.041	2.205	61%	
	2:30	37.06	32.46	Hi 58.5	16.67	17.85	13.3	13.3	2.319	2.411	2.030	1.833	2.094	2.018	2.049	1.836	2.094	1.827	1.831	1.947	1.913	1.953	2.080	2.148	2.264		
								~~13.7~~				1.602	1.746	1.667	1.687	1.592	1.635	1.594	1.553	1.664	1.613	1.674	1.718	1.750	1.718	44%	24 hr [illegible]
	3:30	37.71	32.70	Hi 59.5	16.54	18.27	13.7	13.75	2.324	2.512	2.071	1.848	2.099	2.010	2.055	1.934	2.044	1.917	1.930	1.952	1.899	1.967	2.136	2.235	2.350	57	
	4:30	38.39	32.94	Hi 60.5	16.85	18.50	14.5	14.2	2.390	2.557	2.094	1.872	2.114	2.013	2.005	1.854	2.117	1.842	1.862	2.000	1.941	2.008	2.177	2.305	2.336	57	
	5:30	38.97	33.27	Hi 61.5			14.4	14.0																			
				Lo	13.26	15.14	4.6	4.5	1.861	1.993	1.719	1.592	1.680	1.640	1.634	1.577	1.661	1.585	1.569	1.658	1.632	1.678	1.710	1.743	1.762	31	
	6:30	39.48	33.53	Hi 62	16.62	18.60	13.6	13.6	2.391	2.495	2.060	1.855	2.095	1.944	1.949	1.825	2.003	1.821	1.846	1.999	1.931	1.994	2.202	2.359	2.427	55	
	7:30	40.03	33.78	Hi 63.5	16.53	18.50	13.3	13.3	2.362	2.498	2.046	1.846	2.098	1.933	1.954	1.824	2.080	1.821	1.842	1.990	1.931	1.996	2.183	2.330	2.404	57	1.8 M
	8:30	40.43	33.95	Hi 64.5	16.25	17.92	4.4	4.4	2.241	2.460	2.035	1.845	2.077	1.919	1.932	1.828	2.091	1.822	1.833	1.984	1.926	1.954	2.059	2.131	2.271	55	
	9:30	41.01	34.16	Hi 65.5	16.52	18.31	13.4	13.4	2.424	1.991	1.705	1.587	1.662	1.618	1.621	1.575	1.643	1.581	1.569	1.665	1.626	1.669	1.707	1.744	1.765	53	
	10:30	41.54	34.44	Hi 66.5	16.52	18.37	13.5	13.4	2.421	2.503	2.055	1.841	2.081	1.899	1.931	1.807	2.044	1.805	1.829	1.955	1.880	1.973	2.166	2.341	2.401	54	
	12:30	42.36	34.85	Hi 67.5	16.62	18.66	14.0	13.8	2.455	2.537	2.065	1.842	2.087	1.893	1.945	1.827	2.264	1.821	1.846	1.969	1.812	1.994	1.756	1.785	1.815	45	
	1:33	43.37	35.16	Hi 68.5	16.38	18.17	13.6		2.415	2.537	2.055	1.846	2.090	1.895	1.952	1.824	2.063	1.821	1.852	1.987	1.917	1.997	2.201	2.368	2.427	56	
	3:00	44.20	35.52	Lo 70	13.55	15.11	4.5		1.759	1.942	1.712	1.594	1.701	1.627	1.634	1.585	1.662	1.601	1.585	1.685	1.647	1.694	1.717	1.744	1.762	32	
	4:33	45.07	36.08	Hi 72.5	16.66	18.32	13.5	13.5	2.404	2.527	2.061	1.844	2.109	1.896	1.957	1.822	2.061	1.806	1.836	1.970	1.894	1.980	2.160	2.302	2.371	56%	1.73M (4:44)
	5:30	45.65	36.33	Hi 74	16.58	18.25	13.5	13.5	2.397	2.538	2.062	1.847	2.098	1.894	1.975	1.827	2.064	1.812	1.832	1.962	1.886	1.985	2.164	2.318	2.375	55%	
	6:30	46.17	36.60	Hi 74.5	16.58	18.30	13.5	13.5	1.760	1.962	1.709	1.584	1.693	1.616	1.622	1.580	1.656	1.574	1.565	1.662	1.634	1.680	1.703	1.729	1.744	29%	
	7:30	46.55	36.80	Hi 75.5	16.47	18.36	13.4	13.4	2.381	2.495	2.041	1.840	2.087	1.871	1.940	1.805	1.654	1.501	1.574	1.674	1.635	1.677	1.717	1.751	1.774	45%	1.85M (8:00)
	8:30	46.94	37.13	Hi 76.5	16.64	18.53	13.7	13.7	2.393	2.515	2.044	1.856	2.125	1.894	1.951	1.824	2.067	1.812	1.839	1.978	1.916	1.986	2.212	2.402	1.861	55%	
	9:29	47.39	37.38	Hi 77.5	16.55	18.64	13.4	13.4	2.383	2.514	2.051	1.840	2.101	1.874	1.931	1.823	2.072	1.809	1.841	2.000	1.929	1.976	2.179	1.800	1.850	54%	

TEST NO. 1 — MODULE STATUS — PAGE 4 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	$N_L H_e$ CONC. *	
9-25	1830	4784	37.03	HP	16.64	18.60	13.3	13.3	2.395	2.515	2.053	1.862	2.132	1.889	1.964	1.840	2.082	1.822	1.838	1.996	1.934	2.002	2.238	2.238	2.458	55%		
9-26	12:30	48.73	38.15	HP	18.31	20.5	14.0 35.05	14.2 35.56	3.18	2.907	2.203	1.985	2.135	2.073	2.114	1.995	2.141	1.858	1.884	2.119	2.033	2.115	2.571	3.087	3.112			
									3.42 Volts still climbing								back to Lo Mode											
	1:00	48.80	38.56	Lo 81	13.68	15.04	4.3 10.72	4.4 10.95	1.700	1.725	1.706	1.629	1.966	1.732	1.709	1.624	1.716	1.619	1.593	1.696	1.665	1.617	1.669	1.691	1.697	Pt: 12.15	P_{O_2} = 147	34%
29	1:30	4880	39.09	Lo 91.5	13.73	15.10	4.3 10.74	4.4 10.97	1.697	1.726	1.713	1.638	1.995	1.732	1.701	1.624	1.727	1.630	1.614	1.705	1.670	1.691	1.672	1.687	1.695	12.20	146	41
	2:00	4980	39.56	Lo 92	13.75	15.12	4.3 10.77	4.4 11.02	1.695	1.724	1.709	1.640	1.921	1.731	1.707	1.629	1.733	1.637	1.618	1.703	1.673	1.691	1.678	1.695	1.705	12.50	146	47
34	2:30	4880	40.05	Lo 85	13.82	15.20	4.3 10.77	4.4 11.01	1.703	1.734	1.714	1.648	1.934	1.732	1.715	1.637	1.756	1.645	1.625	1.714	1.675	1.697	1.682	1.695	1.703	12.80	146	51
31	3:30	4473	40.39	Lo 93	13.88	15.13	4.3 10.76	4.4 10.93	1.694	1.721	1.718	1.656	1.970	1.756	1.725	1.640	1.764	1.647	1.625	1.712	1.678	1.693	1.671	1.691	1.695	12.5	152	57
27	4:30	4883	42.02	Lo 94.5	13.94	15.21	4.4 10.67	4.4 10.89	1.695	1.723	1.718	1.658	1.923	1.735	1.735	1.644	1.778	1.652	1.627	1.711	1.678	1.691	1.673	1.691	1.692	12.4	206	61
23	5:30	4883	43.02	Lo 95.5	13.95	15.18	4.4 10.63	4.4 10.89	1.697	1.718	1.714	1.658	2.001	1.742	1.730	1.643	1.744	1.652	1.624	1.710	1.675	1.693	1.662	1.682	1.684	12.6	156	64
	6:30	4883	43.77	Lo 96.5	13.99	15.18	4.4 10.51	4.5 10.81	1.688	1.722	1.716	1.656	2.008	1.827	1.731	1.641	1.785	1.649	1.626	1.702	1.673	1.689	1.673	1.696	1.689	12.5	156	66
	7:30																											

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* [illegible]

TEST NO. 2 IN HOOD WET TEST #3 BIG 24 VDC

SYSTEM STATUS 2 hr

initial H_2O 3960cc
" N_2H_4 1987cc

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) ① MOD	② PI	③ PO_2	④ CAL	⑤ N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	WATER	N_2H_4	META	N_2	ml EIP	GAS ANALYSIS	Meta wet Test
10/27	12:35		1430	28.2	19.0			31.0	4.5	150	2.0	5.75	52°	4.8	.4	7.5	4.5	16.0	0		at 1:30 PM 1884
	3:40	N_2H_4 feed off automatically; set meta & N_2 to correct settings (3.89 cc meta and 12.5 cc for N_2)																			
10/27	4:00		1860	28.2	19.0			36.0	4.5	143	2.0	5.6	48°	6.0	.6		4.0	12.5	10	Meta measure 2332 - Adjusted 3"	
	5:27	N_2H_4 back on														60 cc				4:10 PM now = 2140 cc/m	
	6:00		1815			28.4	6.5	28	4.5	150	2.0	5.75	49°	6.3	0	60 cc	3.5	12.3	45 cc	6:10 PM meta = 2140 cc/m	
	7:00	NOTICE LEAK IN KOH RESERVOIR																			
	8:00		2031			28.5	5.5	33	4.5	159	2.0	5.7	48°	5.6	0	5.5 cc	3.5	12.3	75 cc	8:07 PM meta = 2140 cc/m	
	8:50																			~8.8 cc	
		adjusting N_2H_4 feed to get gas bubbles out																			
	10:00		2221			28.5	19.5	27.5	4.5		2.0	5.8	50°	5.5	.5	6.9 cc	3.5	12.3	90 cc		1934
	11:20	adjusting N_2H_4 feed to 7.0 cc																			
	12:40		2405	28.8	19.8			35	4.5	170	2.0	5.7	48	5.5	—	7.5 cc	3.5	12.5	137 cc	2150 test meter rate	1947
10/28	2:33		2728			28.5	5.2	34	4.5	168	2.0	5.8	48	5.3	—	7.5	3.5	12.5	158 cc		1954.5
	4:34		2913	28.5	20			32	4.6	166	2.0	5.7	47	5.1	.6	7.6	3.5	12.5	184	2150	1964
	6:33		3110	28.6	19.9			29.5	4.5	162	2.0	5.75	47	5.3	.8	9.0	3.5	12.5	208	2150 meter flow	1974
	8:35		327			28.5	5.5	29.0	4.5	158	2.0	5.75	48	4.5	.6	7.5	3.5	12.5	240	2150	1973
	10:35		607	28.5	19.9			29.5	4.6	155	2.0	5.75	48	3.8	.6	7.5	3.5	12.5	270	2150	1982
	12:35		705	28.5	20.0			29.5	4.6	154	2.0	5.70	47	3.5	.6	7.5	3.5	12.4	285	2150	1991
	2:38		884			28.5	5.5	27.5	4.5	150	2.0	5.7	47	3.4	.7	8.0	3.5	12.7	325	2150	2010
	4:34		916	28.5	19.9			29.5	4.5	147	2.0	5.7	44	3.5	.7	—	3.5	12.5	360		[illegible]
10/28	6:15	adjusted N_2H_4 feed ~ 7.5																			2022
	6:34		1136			28.5	5.5	35.5	4.5	152	2.0	5.7	47	4.2	—	7.5	3.5	12.5	460	2150	2035
	8:32		1321	28.5	19.9			35.5	4.5	155	2.0	5.7	48	4.5		7.5	3.5	12.5	470		2044
	10:35		1494	28.5	20.0			35.5	4.5	155	2.0	5.7	47	4.5	.5	7.5	3.5	12.5	480		2054
	10:40	RE-FILL 9.1 CORRECTION CYLINDER															3.5	12.5			
10/29	12:30		1770	24.7	20.1			35	4.4	153	2.0	5.8	47	4.9	.7	7.5	3.5	12.5	46	2140	
	2:30		1961	28.6	19.9	28.5	5.4	34	4.4	152	2.0	5.7	48	4.7	—	8.2	3.5	12.5	80		2062.5
	6:30		2337	24.6	20.3			35	4.2	145	2.0	5.8	46	4.2	.6	6.1	3.5	12.5	154		2071
	7:00	42	Drop N_2H_4 to 5.8																		
	7:20		N_2H_4 off PO_2 = 143																		2080
	8:40		2523			28.5	5.8	34.5	4.5	144	2.0	5.7		3.5	.7	0	3.5	12.5	185	21[illegible]	
	10:40		2618	28.4	20.2			33.5	4.5	150	2.0		50	3.8	.7	5.7	3.5	12.5	220		2099

TEST NO. 2 Hed Wet Test #3 28VDC

SYSTEM STATUS 2 NC

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) ① MOD	② P.T.	③ PO2	④ CAL	⑤ N2H4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N2H4	META	N2	BHF	GAS ANALYSIS N2-O2	CABIN	H2	META wet Test
10/27	12:45		2871			28.5	5.5	35.5	4.5	157	2.0	5.75	47	3.5	.7	5.8	3.5	12.3	240	2090			2108
	2:35		48	28.5	20.5			28.5	4.4	160	2.0	5.60	45	3.3	.7	5.0	3.5	12.6	255				2117
	4:30					27.5	5.5	26.5	4.4	160	2.0	5.8	45	3.0	.7		3.5	12.5	285	2160cc/min			2126
	6:20	53.9	adjusted N2H4 feed													5.8							
	6:55			29.5	20.0			36.0	4.4	158	2.0	5.8	43	3.7	.7	bubbles	3.5	12.5	300	2160cc/min			2136
	8:30	55.5		29.5	20.0			33.5	4.4	158	2.0	5.8	48	4.5			3.5	12.5	400	2160cc/min			2143
	9:00	56.0	PO2 limits ...; N2H4 feed to 11.1 sa ph																				
	10:30	57.5				28.5	5.5	27.5	4.4	156	2.0	5.8	45	4.0	.7	7.9	3.5	12.5	430	2160cc/min			2152
	10:50		N2H4 feed at					7.6 ss		10.9 saph													
	11:00		N2H4 feed at					7.5 ss		10.8 saph													
	11:10		N2H4 feed at					7.4 ss		10.7 saph			; (7.3ss	10.5 saph @ 11:15); (6.9ss 10.0 saph at 11:23)									
	11:26	59.5	N2H4 feed at					6.5 ss		9.5 saph			(11:40	6.0 ss) (11:50 5.8ss)									
10/30	12:15		B.S.	457 cc stop						1020 now start													2162
	12:30		1047	28.6	20.2	28.7	5.2	27.5	4.3	151	2.0	5.75	46	4.0	18	6.0	3.5	12.5	113	2140 cc/min			2162
	2:30		1257	28.6	20.1			34	4.3	149	2.0	5.7	46	4.0	.7	5.6	3.5	12.5	173				2171
	4:30		1455			28.6	5.4	34	4.3	150	1.9	5.75	45	3.8	—	7.1	3.5	12.5	205	2150			2189
	6:30		1662			28.7	21	27	4.3	148	1.9	5.7	46	4.1	.7	7.6	3.5	12.5	255				2199
	8:30		1797	28.5	21.2			34.5	4.3	146	1.9	5.7	46	4.0	.7	7.6	3.5	12.5	330				2208
	10:30		2011			28.5	21.5	34.0	4.5	143	1.9	5.7	45	3.7	.7	—	3.5	12.5	400				
	11:00			OFF (N2H4 off; cell in manual high mode w/ N2 purge)																			

Sensor calibration check: PO2 data 118 in air; PO2 control 118 in air; PO2 effluent 160 in air } same as original settings

Water tank contained 2290 cc

N2H4 tank contained 870 cc + 24 cc est in lines

Tests (4:10PM)
O2/N2 effluent 64.1% O2, 35.9% N2
no H2 detected (≤.1% limit)
Cabin atm. no H2 detected.
B.S. – 28.3% H2, 40% O2, 31% N2

TEST NO. 2

MODULE STATUS

HRLY

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DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC. *	
p.m. 10/27	12:35	51.76	47.03	Hi	14.98	16.48	12.7	12.8	1.926	1.858	1.896	1.921	1.993	1.804	1.852	1.768	1.814	1.814	1.792	1.845	1.816	1.828	1.841	1.866	1.891	590 mm	—	avg 1.818
10/27	1:30	52.18	47.39	Hi [0.5]	15.13	16.65	12.7	12.8	1.923	1.871	1.916	1.932	2.001	1.822	1.878	[LO] 1.583	1.612	1.621	1.591	1.634	1.615	1.627	1.635	1.660	1.686	460 mm	0.66	(1:27)(10cc)
10/27	2:30	52.39	47.81	Hi [1.5]	15.27	16.90	12.7	12.8	2.008	1.917	1.919	1.942	2.021	1.823	[LO] 1.649	1.577	1.607	1.615	1.587	1.643	1.626	1.646	1.659	1.682	1.716	380 mm	1.25	(2:34)(10cc)
10/27	3:30	52.89	48.16	Hi [2.5]	15.34	17.08	12.7	12.8	1.711	1.673	1.654	1.637	1.670	1.601	1.626	1.573	1.603	1.616	1.584	1.647	1.627	1.645	1.660	1.679	1.709	300 mm	1.71	(3:30)(10cc)
"	4:30	53.09	48.40	Hi [3.5]	15.50	17.21	12.7	12.9	1.996	1.943	1.937	1.964	2.105	1.837	1.907	1.792	1.849	1.861	1.602	1.673	1.645	1.656	1.670	1.691	1.722	380 mm	1.83	(4:33)(10cc) (?)
"	5:30	53.71	48.77	Hi [4.5]	15.54	17.25	12.7	12.9	2.009	1.951	1.938	1.975	2.104	1.840	1.911	1.799	1.848	1.870	1.831	1.935	1.901	1.918	1.944	1.975	2.012	510 mm		
"	6:30	54.32	48.94	Lo [5.5]	13.30	14.93	4.3	4.3	1.693	1.687	1.664	1.662	1.729	1.61[illegible]	[Hi] 1.910	1.734	1.847	1.872	1.837	1.937	1.902	1.915	1.936	1.958	1.992	500	1.07	(6:45)(10cc)
"	7:30	54.87	49.25	Hi [6.5]	15.62	17.41	12.7	12.9	2.010	1.959	1.940	1.995	2.126	1.841	1.917	1.794	1.858	1.881	1.837	1.947	1.910	1.932	1.961	[LO] 1.718	1.750			
"	8:30	55.54	49.59	Hi [7.5]	15.60	17.29	12.8	12.9	2.000	1.951	1.946	2.008	2.142	1.850	1.932	1.805	1.867	1.884	1.841	1.957	1.915	1.932	1.965	2.001	2.052	510 mm		
"	9:30	55.94	49.74	Lo [8.5]	13.41	15.03	4.3	4.3	1.717	1.698	1.661	1.675	1.740	1.621	1.654	1.589	1.623	1.640	1.606	1.677	1.654	1.666	1.682	1.699	1.73	410 mm	1.07	(9:48)(10cc)
	10:35	56.53	50.08	Hi [9.5]	13.52	15.21	[LO] 4.2	4.3	1.744	1.715	1.664	1.675	1.748	1.619	1.652	1.591	1.629	1.646	1.607	1.687	1.662	1.678	1.686	1.717	1.750	405	.57	10:40 (ADD 60 cc KOH)
	11:30	56.98	50.37	Hi [10.5]	15.67	17.47	12.8	13.0	2.055	1.982	1.944	2.022	2.147	1.890	1.912	1.803	1.863	1.887	1.896	1.970	1.935	1.962	1.999	2.052	2.102	510	1.08 (10.48)	(10cc)
10-28	12:00	N_2H_4 @ 7.4 much Gas bubbles → float increased to 8.0 still bubbles																										
	12:30	57.46	50.68	Hi	15.71	17.57	12.8	13.0	2.058	1.982	1.947	2.020	2.143	1.845	1.909	1.802	1.859	1.887	1.844	1.965	1.[illegible]							
				Lo	13.35	15.07	4.3	4.4	1.743	1.712	1.663	1.669	1.738	1.615	1.644	1.586	1.621	1.642	1.607	1.689	1.674	1.680	1.701	1.727	1.769	340		
	1:30	58.03	50.91	Hi [12.5]	15.74	17.63	12.8	13.0	2.078	1.995	1.948	2.024	2.141	1.847	1.94	1.800	1.860	1.872	1.852	1.981	1.947	1.969	2.007	2.061	2.109	470		
	2:30	58.65	51.14	Hi [13.5]	15.76	17.67	12.8	13.0	2.085	1.999	1.948	2.027	2.149	1.844	1.908	1.800	1.852	1.884	1.845	1.978	1.950	1.979	2.016	2.023	2.117	460	2:47	(1.53 M N_2H_4)
	3:30	59.08	51.37	Hi [14.5]	15.71	17.76	12.75	13.0	2.101	2.011	1.947	2.011	2.114	1.839	1.900	1.791	1.848	1.871	1.850	1.992	1.954	1.984	2.032	2.077	2.135	450	Mods 2-5 ck 3:40 ok	
	4:30	59.70	51.59	Hi [15.5]	15.71	17.68	12.75	13.0	2.091	2.001	1.947	2.023	2.127	1.840	1.894	1.793	1.846	1.870	1.848	1.988	1.955	1.943	2.033	2.091	2.1[illegible]	445		
	5:30	60.17	51.81	Hi [16.5]	15.7	17.68	12.8	13.0	2.091	2.002	1.951	2.021	2.114	1.841	1.897	1.785	1.842	1.890	1.849	1.988	1.951	1.984	2.034	2.094	2.155	445	5:44	(1.73 M N_2H_4)
	6:30	60.38	52.17	Hi [17.5]	15.58	17.61	12.8	13.0	2.042	1.980	1.953	2.020	2.109	1.846	1.888	1.793	1.841	1.890	1.848	1.977	1.940	1.967	2.002	2.043	2.088	440		
	7:30	61.42	52.56	Hi [18.5]	15.68	17.84	12.8	13.0	2.099	2.007	1.949	2.022	2.099	1.835	1.875	1.783	1.835	1.884	1.854	2.001	1.959	2.009	2.065	2.127	2.188	442		
	8:30	61.78	52.86	Hi [19.5]	15.67	17.76	12.8	13.0	2.102	2.000	1.951	2.026	2.090	1.837	1.872	1.786	1.834	1.880	1.854	1.994	1.959	2.009	2.066	2.132	2.187	442		
	9:30	62.16	53.24	Hi [20.5]	15.63	17.83	12.8	13.0	2.117	2.009	1.954	2.015	2.052	1.836	1.874	1.791	1.839	1.888	1.849	2.011	1.972	2.023	[LO] 1.744	1.773	1.809	285		
	10:30	62.64	53.61	Hi [21.5]	15.48	17.89	12.8	13.0	2.065	1.972	1.967	2.023	2.040	1.827	1.855	1.769	1.821	1.878	1.843	1.994	1.968	2.013	2.055	2.111	2.152	460		
	11:30	63.16	53.88	Lo [22.5]	13.15	15.26	4.4	4.8	[Hi] 2.103	1.986	1.995	2.043	2.051	1.812	1.837	1.764	1.817	1.871	1.842	1.987	1.975	2.049	2.099	2.174	2.208	470		
	12:30	63.69	54.01	Lo [23.5]	13.08	15.21	12.8	13.0	1.764	1.691	1.668	1.652	1.637	1.574	1.581	1.545	1.581	1.614	1.581	1.675	1.669	1.726	1.752	1.785	1.819	450		
	1:30	64.15	54.30	Hi [24.5]	15.56	18.11	12.8	13.0	2.112	1.985	1.997	2.040	2.041	1.807	1.832	1.767	1.816	1.869	1.834	1.982	1.971	2.054	2.110	2.204	2.244	460		
	2:30	64.59	54.74	Hi [25.5]	15.38	17.98	12.8	13.0	2.091	1.961	1.966	1.983	[LO] 1.633	1.556	1.570	1.508	1.577	1.601	1.558	1.665	1.657	1.722	1.753	1.797	1.836	260		
	3:30	65.01	55.03	Hi [26.5]	15.41	18.09	12.8	13.0	[LO] 1.771	1.691	1.664	1.635	1.622	1.549	1.564	1.527	1.586	1.605	1.562	1.662	1.656	1.718	1.751	1.797	1.833	450		
	4:10	N_2 makeup bottle was empty — back on line at 4:20																										
	4:25	H_2O Feed																										

* EVERY 4 HOURS

TEST NO. 2 — MODULE STATUS — HRLY — PAGE 2 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A*	4A*	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC. *
10/28	4:30	6569	5539	HI[46]	15.28	18.28	12.8	13.1	2.117	1.561	1.951	2.006	1.977	1.771	1.791	1.733	1.782	1.843	1.805	1.952	1.948	2.065	2.173	2.361	2.419	440 mm	
"	5:36	6610	5576	LO[34]	13.51	15.30	4.3	4.3	1.750	1.697	1.673	1.692	1.702	1.604	1.615	1.578	1.611	1.641	1.609	1.693	1.681	1.722	1.741	1.771	1.794	370 mm	.98M (6.01 M, 10cc)
"	6:30	6651	5594	HI[32]	15.83	17.94	12.8	13.0	2.074	2.001	1.983	2.078	2.140	1.860	1.904	1.811	1.872	1.898	1.862	2.013	1.973	2.008	2.085	2.201	2.225	530 mm	
	7:30	67.12	56.34	HI[30]	15.85	18.04	LO 4.3	13.0	LO 1.761	1.731	1.678	1.685	1.739	1.627	1.643	1.593	1.632	1.652	1.615	1.708	1.680	1.702	1.723	1.753	1.788	410 mm	
	8:30	67.59	56.80	LO[31.5]	13.30	15.31	4.3	4.3	1.748	1.717	1.672	1.681	1.706	1.620	1.631	1.589	1.627	1.649	1.614	1.708	1.683	1.707	1.719	1.743	1.765	330 mm	
	9:30	68.06	57.02	LO[32]	13.33	15.23	4.3	4.4	1.737	1.709	1.674	1.672	1.705	1.620	1.633	1.583	1.621	1.643	HI 1.856	2.008	1.975	2.009	2.043	2.093	2.109	410 mm	
	10:31	68.54	57.44	HI[32]	15.78	17.97	12.8	13.0	2.067	2.001	1.987	2.054	2.118	1.857	1.893	1.808	1.871	1.902	1.860	2.017	1.979	2.013	2.068	2.154	2.187	470	
	11:30	69.12	57.96	HI[34]	15.69	17.96	12.9	13.1	2.075	2.009	1.991	2.074	2.121	1.858	1.893	1.808	1.868	1.908	1.863	2.018	1.982	2.016	2.061	2.132	2.149	470	
10/29	1230	69.60	58.12	LO[35] 13:30 14:47	15.28		4.35	4.4	1.737	1.727	1.663	1.684	1.648	1.601	1.605	1.583	1.605	1.640	1.587	1.717	1.630	1.725	1.758	1.795	1.820	280	
				HI	15.26	18.37			2.165	2.024	1.923	2.060	2.094	1.843													
	1:30	70.44	58.52	HI[36]	15.81	18.01	12.9	13.2	2.082	2.014	1.987	2.073	2.115	1.858	1.890	1.804	1.857	1.903	1.864	2.048	1.988	2.013	2.076	2.157	2.178	430	
	2:30	70.93	58.93	HI[37.5]	15.81	18.48	12.9	13.2	2.169	2.038	1.980	2.053	2.023														
					13.16	15.36	11:03 4.3	11:04 4.4	1.771	1.717	1.668	1.653	1.639	1.546	1.574	1.545	1.600	1.631	1.580	1.717	1.692	1.754	1.793	1.772	1.819	215	
	3:30	71.50	59.06	HI[38.5]	15.88	18.39	12.9	13.2	2.168	2.047	1.982	2.053	2.094	1.849	1.872	1.799	1.852	1.896	1.861	2.043	2.005	2.071	2.155	2.203	2.213	456	
	3:50	N$_2$H$_4$ Rinse out																									
	4:20	set N_2 in to 13.5 + help hold in low current																									
	4:50	Back on w/ N_2H_4 (tank filled 1965cc only 64% N_2H_4) flow set high to restore CaH_4																									
~~6:35~~		old N_2H_4 fed			7.5 ± 1.5		cc/hr		with 65% fuel		new = 1.0		shift 6:55			6:20 AM											
	5:30	72.22	59.99	HI[40.5]	15.74	18.12	12.9	13.2 12.9	2.079	2.041	2.000	2.045	2.108	1.844	1.868	1.793	1.857	1.898	1.871	2.039	2.000	2.036	2.083	2.174	2.194	470	
	6:30	72.67	60.33	HI[41]	15.75	18.28	12.9	13.2	2.102	2.015	1.996	2.073	2.091	1.839	1.862	1.785	1.840	1.901	1.872	2.047	2.008	2.050	2.103	2.252	2.270	445	
	7:30	73.32	60.61	LO[42.5]	13.09	15.33	4.4	4.3	1.772	1.709	1.667	1.639	1.628	1.574	1.574	1.533	1.580	1.628	1.601	1.715	1.698	1.737	1.752	1.792	1.822	210	
	8:30	73.73	61.06	HI[43.5]	13.22	15.42	LO 12.8	13.2	LO 1.770	1.706	1.673	1.669	1.654	1.588	1.589	1.552	1.589	1.622	1.599	1.698	1.685	1.733	1.752	1.795	1.825	290	
	9:30	74.35	61.38	HI[44.5]	13.37	15.33	12.8	13.2	1.760	1.707	1.685	1.699	1.720	1.616	1.622	1.576	1.616	1.640	1.611	1.701	1.691	1.731	1.743	1.781	1.807	420	
	10:30	74.99	61.78	HI[46]	15.93	18.19	12.8	13.2	2.057	2.004	2.011	2.133	2.164	1.856	1.895	1.808	1.874	1.897	1.861	2.022	1.99	.016	2.086	2.228	2.261	540	
	11:30	75.14	62.16	HI[46.5]	15.98	18.20	12.9	13.2	2.059	2.009	2.027	2.142	2.172	1.869	1.912	1.808	1.889	1.908	1.873	2.037	1.991	2.027	2.084	2.219	2.225	550	
	12:30	75.64	62.45	HI[47.5]	15.84	18.21	12.8	13.2	2.099	1.986	2.019	2.125	2.155	1.843	1.881	1.784	1.856	1.880	1.850	1.998	1.972	2.054	2.123	2.288	2.303	530	
	1:30	76.23	62.87	HI[48]	15.90	18.41	12.8	13.2	2.109	2.012	2.033	2.133	2.146	1.847	1.880	1.787	1.864	1.890	1.858	2.027	1.999	2.071	2.148	2.329	2.356	520	
	2:30	76.86	63.06	HI[49]	15.76	18.48	12.8	13.1	2.124	1.994	2009	2.087	2.126	1.821	1.847	1.758	1.831	1.860	1.832	1.985	1.966	2.087	2.202	2.431	2.484	480	
	3:30	77.28	63.44	HI[50]	15.75	18.28	12.8	13.0	2.105	1.998	2.019	2.093	2.116	1.820	1.846	1.747	1.817	1.833	1.811	1.929	1.911	2.047	2.178	2.411	2.472	480	
	3:40	Dropped Chiller Temp to 35° F																									
	4:30	77.60	63.79	HI[51.5]	15.68	18.01	12.8	13.1	2.089	1.984	2.012	2.094	2.115	1.827	1.851	1.768	1.833	1.872	1.838	1.992	1.975	2.067	2.164	2.315	2.354	480	

* EVERY 4 HRS

C-11

TEST NO. 2

MODULE STATUS

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT POT	N_2H_4 CONC. *
					3252	3309																					
10/29	5:30	78.19	64.85	H-A85	15.58	18.26	12.8	13.0	2.102	1.982	1.998	2.059	2.082	1.798	1.815	1.732	1.807	1.929	1802	1.935	1915	2.051	2.181	2 381	2.432	460	
	6:55	78.96	64.49	H P																							
	7:25	79.17	64.66	H P	15.84	18.59	13.0	13.4	2.133	2.030	2.002	2.086	2.097	1.843	1.864	1.787	1.944	1.897	1.868	2.062	2.017	2.077	2.211	2.369	2.379	460	
	8:30	79.88	64.99	H P	15.92	18.91	12.9	13.1	2.142	2.034	2.002	2.106	2.117	1.856	1.877	1.993	1.935	1.898	1.867	2.054	1.990	2.050	2.182	2.318	2.354	465	
	9:30	80.52	65.32	H O	13.25	15.29	4.3	4.4	1.765	1.719	1.674	1.657	1.661	1.610	1.611	1.587	1.607	1692	1.610	1.570	2.035	2.009	2.055	2.113	2.176	450	
	10:30	81.07	65.62	H	15.59	18.32	13.0	13.3	2.149	2.020	2.005	2.066	2.031	1.837	1.848	1.767	1.826	1.881	1.855	0462	2.023	2.102	2.188	2.339	2.356	430	
10/30	12:00			N_2H_4	Set	to	6.5	SS																			
	12:30	82.12	66.20	H	15.82	19.06	13.1	13.3	2.195	2043	2.064	2.065	2034	1.833	1.852	1.776	1.812	1.882	1.855	2.085	2.046	2135	2.311	2.463	2.549	420	
	1:30	82.63	66.48	H	15.91	19.75	13.0	13.1	2.164	2.040	2.019	2.083	2.080	1.856	1.869	1.798	1.831	1.893	1.863	2.070	2.030	2.105	2.265	2.407	2.455	450	
			N_2H_4 ~	6.4	SS	+	very	small	bubble																		
	2:30	83.31	66.76	H	15.94	18.78	13.0	13.4	2.145	2.030	2.025	2.091	2.079	1.843	1.853	1.786	1.824	1.891	1.859	2041	2.041	2.129	2.300	2.448	2.520	450	
	3:10	Raise	N_2H_4	to	7.0	SS																					
	3:30	83.84	67.08		13.19	15.32	4.3	4.4	1.779	1.707	1.682	1.651	1.647	1.577	1.594	1.554	1.586	1.625	1.595	1.766	1.636	1.744	1.752	1.782	1.817	255	
	4:30	84.25	67.39	H	16.0	19.48	13.0	13.3																			
				4.0	13.2	15.35	4.3	4.4	1.790	1.714	1.680	1.643	1.632	1.579	1.590	1.555	1.587	1.624	1.586	1.709	1.636	1.746	1.757	1.792	1.825	235	
	5:30	84.75	67.75	H	15.98	19.28	13.2	13.4	2.210	2051	2.015	2.094	2.089	1.851	1.862	1.799	1.835	1.900	1.867	2.111	2062	2.156	2.360	2.498	2.580	430	
	6:30	85.36	68.01	H	15.92	18.93	13.1	133	2.192	2034	2.034	2.101	2.091	1.848	1.862	1.790	1.823	1.891	1.858	2.083	2.058	2.153	2.301	2.447	2.505	430	
	6:52	N_2H_4	flow	0	11.0	SCFH	— reduced	to	10.0	~	6.9	SS															
	7:16	O_2	5	cfh	reduced	N_2H_4	to	6.5	SS																		
	7:30	85.91	68.30	H	15.92	19.32	13.2	13.4	2.222	2.047	2.029	2.101	2.066	1.829	1.849	1.782	1807	1.877	1.851	2079	2059	2187	2.420	1833	1878	260	
	8:30	86.55	68.65	H	15.88	18.79	13.0	13.4	2.191	2.029	2.028	2.090	2.092	1.838	1858	1.786	1.821	1.886	1.857	2094	2057	2.145	2.300	2.453	2.501	420	avg = 2.055
	9:30	86.97	68.98	O_2	15.59	18.26	13.0	13.2	2.172	2.033	2.032	2.103	2079	1.839	1.855	1.788	1.817	1.887	1.854	2083	2052	2143	2270	2404	2447	430	
	10:30	87.53	69.12	O_2	12.57	19.04	4.5	4.5	1.729	1.705	1.661	1.587	1.576	1.395	1.434	.909	1.531	1.850	1.820	1998	2.007	2107	2181	2270	2304	410	

* EVERY ♣ HOURS

TEST NO. 3 SYSTEM STATUS 24 hr PAGE 1 OF

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) MOD	PT	PO2	CAL	N2H4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N2H4	META	N2	BUB. SEP.	GAS ANALYSIS N2-O2	CABIN	H2	meta
11-?	10:08		N_2H_4 feed on at 10.08 a.m; set high @ 11.0 ss; 500 on valve meta																				
	10:30		221?	28.5	19.?			41	4.5	152	1.9	5.9	55	5.5	.7	11.0ss	4.2ss	16ss	45	2720cc/min			
am	11:30		218?			28.5	5.5	43.5	4.5	151	1.9	5.9	51	5.5	.7	10.5 500V	4.2ss	16ss	45	2720cc/min			222x1
pm	12:30	0														400V	3.5ss	12.5ss		2140 cc/min			
	12:45	:45	430			28.5	5.5	46.5	4.5	145	1.9	5.8		6.2	.7	7.5ss 400V	3.5	12.5	50	2130 cc/min			2227
	1:06	1:06	N_2H_4 feed cycled off; ΔN_2' = 425cc 1st cycle																				
	1:55	1:55	550	28.4	19.8			34.5	4.5	141	1.9	5.8	47	7.8	.7	-0-	3.5	12.6	70	2130cc/min			2233
	4:05	4:05	774	28.5	19.9			38.5	4.3	142	1.9	5.9	47	6.3	—	-0-	3.5	12.35	85				
	4:45	4:45	Quiet 3.35 min =2110 reset to 2190																				
	5:58		N_2H_4 on c valve stuck open @ 6:10 with flow																				
	6:17		10 cc N_2H_4 sample taken																			78M	
	6:23	6:23	950	28.6	20.0			27	4.3	155	1.9	5.8	48	6.7	0	120 9.0ss	3.6	12.5	105				
	8:00	8:06	1108			28.6	5.5	31	4.3	157	1.9	5.8	46	6.5	0	high	3.5	12.5	110	2190 cc/min			2251
	8:00	Note	gain ~ 2 in in pool, no feed in 1 hr																				
	8:30	Note	N_2H_4 in 30 min gained 1 in. Reduce flow to 390 (from 400) to food hold line 8.85s to 7.75s																				
	9:30	Note	new N_2H_4 resulted in drop of about 1" in 1hr																				
	10:00	10:00	1348	28.7	20.8	28.4	5.2	35	4.3	154	1.9	5.8	43	5.5	?	?	13.6	12.5	135	2190 cc/min			2260
	10:10	Note	level now dropping fast and effluent composition level off & climbing — back to 400 N_2H_4 valve setting																				
	11:30		POL soft. Reduce N_2H_4 flow to 393 ~ 8.0 ss note level holding on																				
mid	12:00	12	1591			28.5	5.5	32	4.5	150	1.9	5.8	42	6.1	—	—	3.5	12.5	163				
am	2:00	14	1625	28.5	20.8			37.5	4.5	147	1.9	5.8	42	6.0	.5	7.9	3.5	12.5	187				2180
	3:16		Reduce N_2H_4 flow to 392 ~ 7.9 ss																				
	3:25		drain N_2H_4 tank; add 600 cc to bring total volume to 2 liters (2000 cc)																				2200 cc
			ΔV = 580 cc																	1980			
	4:02	16	1817			28.5	5.8	27	4.5	144	1.9	5.8	42	4.8	—	—	3.5	12.5	225				
	4:30		B.S. at 230 cc, pump up to 25 cc																				
	6:00	18	2092	28.5	20.5			36	4.5	152	1.9	5.8	42	3.5	.7	—	3.5	12.5	55				
	8:00	20	2391			28.5	5.5	34	4.5	160	1.8	5.6	43	4.3	7	7.75	3.5	12.4	85				2318
	8:50	21	Bubble separator level raised from 100 to 75																	3.26 2172 cc/min			
	10:00	22	2589	28.5	21.0			31	4.5	157	1.6	5.75	42	4.5	7.5	8.0	3.5	12.4	95	3.26 2160			2326
	10:15		Bubble separator level raised from 100 to 75																				

TEST NO. 3 SYSTEM STATUS PAGE 2 OF __

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) MOD	P.T.	PO_2	AL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	ANT N_2H_4	META	N_2		GAS ANALYSIS N_2 O_2	
11-11	1200	24	2847	28.6	21.8			35	43	154	1.9	5.9	43	4.7	.7	70cc	3.6	12.5	120 2130	2335
	12:38	Bubble sep raised to 50cc mark from 125cc																	2160	
	2:00	N_2H_4 feed off						4		145	1.8	5.7								
	2:10		3003					41	4.5	145	1.8	5.7	43	4.5	.7	-	3.5	12.5	85 2155 cc/min	2344
	2:50	Charged N_2H_4 Tank with 510 cc																		
	3:20	Raised Bubble Sep. level From 115 to 50																		
	4:00	28	0231	28.5	21.0			32.5	4.5	145	1.8	5.8	43	3.5	.7	-	3.5	12.4	60	2353
	5:55	Noted Incomplete water feed													.7		~~3.5~~	~~12.9~~		
	6:00	30	0.399	27.7	20.8			29	4.3	149	1.9	5.8	48	4.2	.7	0	3.5	12.7	35 330 2150 cc/m	2362
	6:05	N_2H_4 feed start								8.0ss @ start										
	6:10	10 ml Sample of electrolyte										.78M checks with 11-10 gas sample								
	8:00	32	0589	27.7	21.0	28.6	5.5	36	4.3	13.8	1.9	5.8	47	4.3	.8	8.2	3.6	12.5	40 330 2150 cc/m	2372
	10:00	34	0787	28.5	21.0			36	43	155	1.9	5.8	42	4.8	.7	8.2	3.6	11.7	45 329 2150	2380
	12:00	36	0812			28.5	5.6	28	43	158	1.9	5.8	42	4.5	.7	8.2	3.6	12.5	55	
	~~[illegible]~~17					ΔV ≈ 410 cc N_2H_4 ~~added~~ used up in last cycle														
	2:00	38	1141		~~28~~	28.5	5.8	34	43	144	1.9	5.8	42	3.5	.7	—	3.5	12.4	95 2160 cc/m	
	4:00	40	1322			28.5	5.8	31	4.3	149	1.9	5.8	42	3.1	—	—	3.5	12.5	115	2417
	6:00	42	1410			285	5.9	34.5	4.3	159	1.9	5.8	42	3.3	.7		3.5	12.5	130 2130 cc/m	
	6:45						Noticed N_2H_4 feed motor, fiddled w/ solenoid sticking & pO_2 control to get it started.													
	8:15	44.5	1700			28.5	5.5	37	4.8	168	1.9	5.75	43	3.8	.7	-	3.5	12.5	150	2421
	8:20	44.5	Raised bubble sep. level From 150 to 50													8.3	~~3.5~~	~~12.4~~	335 2110 cc/min	
	10:00	46	1961			28.7	21.7	36.5	4.6	162	1.8	5.8	45	4.0	.7	8.3	3.5	12.4	75 335 2110 cc/m	2435
11-[illegible]	12:00	48	2066			28.5	5.5	35	4.6	155	1.8	5.8	42	3.8	.7	7.5	3.5	12.5	85 2110 cc/min	2445
	1:20	Raised bubble Sep. level from 110 to 50																		
	1:25	Reached lower control point (145) - shut off																		
	1:33	Electrolyte sample drawn 10cc												2.5 [illegible] 2.7 M		2 titrations	dif. stds.			
	2:20	Charged N_2H_4 Tank with 425 cc																		
[illegible]	2:30	50.5	2133	28.5	21.5			[illegible]	4.6	142	1.8	5.75	42	3.5	.7	-	3.5	12.5	65 326 2170 cc/min	2456
	4:00	52	2423	28.5	21.5			34	4.6	145	1.8	5.8	42	3.3	.7	-	3.5	12.4	75 325 2170 cc/min	2462
	~~[illegible]~~	~~54~~	~~5:30~~	N_2H_4 on				39	44	156	1.8	5.8	46		.7		3.5	12.5	out	24[illegible]
	7:00	58	2850																	

TEST NO. 3 SYSTEM STATUS PAGE 3 OF __

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	POWER INPUT HIGH AMPS	POWER INPUT LOW VOLTS	POWER INPUT LOW AMPS	PRESSURE (PSIG) MOD	PT	P_{O_2}	CAL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N_2H_4	META	N_2	BUB 'E'	GAS ANALYSIS N_2-O_2	CABIN	H_2	
11-12	8:00AM	56	2958			28.5	5.2	39	4.4	156	1.9	<	46	3.5	.7	7.8	3.5	12.5	—	3.28 2150 cc/m			2481
	10:00	58	0161	29.6	21.8			34.5	4.5	152	1.8	5.8	47	4.5	0	8.2	3.6	12.6	—	3.25 2150			2490
		Note ~ 8:00 PM P_{tot} control dropped slightly																					
	10:58	Note N_2 in @ 130 back to 12.5																					
	11:30	N_2H_4 flow 8.0																					
12:00-60	11:41	N_2H_4 flow Off																					
	12:2[illegible]	ΔV N_2H_4 added = 370 cc																					
	12:21	60.3	0312	28.5	20.8			39	4.4	154	1.9	5.8	43	3.2	.7	—	3.5	8.4					2501
	12:24		new N_2 tank (N_2 makeup) on line, correct P_{total} to 12.4																				
62	2:00		0528			28.5	5.6	42	4.4	144	1.9	5.8	43	3.2	.7	—	3.5	12.5	—				2518
64	4:00		0717			28.5	5.8	35	4.4	154	1.9	5.8	43.5	3.2	.7	~8	3.5	12.5	—				2517
66	6:00		0906	28.5	21.8			34.5	4.4	161	1.9	5.8	43	3.5	.7	~8	3.5	12.5	—	2150 cc/m			2[illegible]6
68	8:00		1185	28.5	20.5			35.5	4.6	160	1.8	5.8	43	3.2	.7	—	3.5	12.5	—	3.27 2150 cc/m			25[illegible]5
70	10:00		1413	28.5	21.8	28.5	5.5	35.5	4.6	155	1.8	5.8	42	3.8	.7	~8	3.5	12.5	—	3.26 2150 cc/m			2545
72	12:00		1640			28.5	5.5	37	4.6	150	1.8	5.8	42	3.8	.7	—	3.5	12.5	—	3.26 2150 cc/m			2555
74	2:00		1763	28.5	20.5	28.5	5.5	31	4.6	148	1.8	5.8	42	3.5	.7	—	3.5	12.5	—	3.26 2150 cc/m			2563

End of Test

ΔN_2H_4 = 585 cc

Drained H_2O tank ΔH_2O = 2330 cc

P_{O_2} C 117.5 final cal. in air

P_{O_2} D 118 final cal in air

P_{O_2} effluent 120 final cal in air

TEST NO. 3 — MODULE STATUS — PAGE 1 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFICIENT POL	NLM & COMM *	
11-10	10:36	9362	69.60	HI	15.18	17.01	12.75	12.90	1.995	1.916	1.897	1.877	1.931	1.830	1.928	1.824	1.830	(1.835)	1.815	1.914	1.857	1.995	1.934	1.948	1.994	640		10.38(10cc)
	11:35	94.26	69.80	HI	15.19	17.24	12.80	13.0	2.065	1.954	1.901	1.887	1.905	1.815	1883	1.807	1.810	1.893	1921	1.951	1.891	1938	1.985	2.008	2073	530	[illegible] M	11.04(10cc)
—	2:05	95.10	70.47	LO	13.09	14.85	4.3	4.3	1.695	1.676	1.666	1.625	1.698	1.824	1886	1.816	1.828	1.861	1.833	1.967	1.915	1.948	1.980	1991	2.037	440	2.0 M	12.04(10cc)
	3:00	95.32	70.76	Lo	13.18	14.90	4.2	4.3	1.624	1.679	1.671	1.642	1.673	1.604	1.638	1.582	1.601	1.648	1.587	1.672	1.905	1.932	1.967	1.981	2.042	350		
	4:00	95.86	71.11	Hi	15.52	17.58	13.0	13.2	2.067	1.994	1.954	1.941	2.008	1.878	1912	1.818	1857	1.877	1.839	1.991	1.939	1.969	2.012	2.045	2.088	540		
	5:00	96.15	71.27	Hi	15.63	17.75	13.0	13.2	2.081	2.016	1.961	1.961	2.031	1.848	1.907	1.823	1.865	1.901	1.854	2.004	1.946	1.974	2.014	2.067	2.112	570		
	6:00	96.85	71.52	Hi																								
	6:20	96.94	71.54	Hi	15.64	17.85	13.0	13.2	2.083	2.026	1.966	1.969	2.039	1.841	1.892	1.823	1.865	1.904	1.861	2.017	1.952	1.985	2.027	2.094	2.136	590	.78M (6:17-10cc)	
	7:00	97.36	71.73	Hi	15.55	17.86	13.0	13.2	2.098	2.033	1.963	1.947	1.975	1.831	1.881	1.816	1.859	1.893	1.857	2.046	1.958	1.992	2.033	2.110	2.149	560		
	8:00	97.83	72.00	Hi	15.5	18.07	13.1	13.3	2.132	2.066	1.957	1.937	1.932	1.812	1.842	1.570	1.594	1.630	1.593	1.711	1.627	1.705	1.767	1.777	1.821	510		
	9:00	98.46	72.36	Hi	15.49	17.54	13.1	13.3	2.039	2.[illegible]	1.966	1.952	1.948	1.818	1.864	1.811	1.826	1.831	1.848	2.020	1.970	2.002	2.040	2.125	2.[illegible]	480		
	10:00	99.08	72.54	Hi	15.53	18.43	13.2	13.3	2.228	2.113	1.962	1.948	1.899	1.785	1.830	1.776	1.788	1.870	1.847	2.061	2.008	2.070	2.137	2.320	2.412	470		
	11:00	99.55	72.81	Lo	12.37	15.03	4.6	4.5	1.768	1.729	1.666	1.628	1.605	1.400	1.531	1.770	1.814	1.880	1.849	2.038	1.985	2.032	2.078	2.143	2.174	160/450		
11-11	12:00	9995	73.00	HI	1461	17.10	13.2	13.4	2.256	2.177	1.980	1.913	1.903	1.793	1837	1.759	1.819	1.885	1.855	2103	2.045	2.107	2195	2.286	2.981	410		
	1:00	100.35	73.20	LO	12.34	14.97	4.6	4.5	1.816	1.753	1.672	1.630	1.608	1.219	1.506	1.397	1.538	1.591	1.514	1.699	1.678	1.725	1.743	1.792	1.819	170		
	2:00	101.63	73.56	HI	15.66	18.22	12.9	13.2	2.211	2.132	1.976	1.981	1.967	1.797	1.850	1.788	1.805	1.871	1.841	2.066	2.013	2.[illegible]	2.156	2.323	2.408	15		
	3:00	101.90	73.83	HI	15.77	18.86	13.1	13.4	2.284	2.207	1.972	1.947	1.922	1.803	1.839	1.785	1.787	1.843	1.850	2.110	2.054	2.115	2.235	2.449	2.555	120		
	4:00	102.13	74.10	HI	15.98	19.11	13.2	13.4	2.300	2.233	1.699	1.634	1.619	1.472	1.547	1.508	1.545	1.578	1.490	1.718	1.691	1.744	1.767	1.817	1.849	30	2.15 M	2:55(10cc)
	5:00	102.66	74.43	LO	15.71	18.03	12.9	13.2	2.155	2.081	1.986	1.994	2.083	1.863	1.878	1.805	1.812	1.873	1.844	2.044	2.001	2.053	2.131	2.222	2.262	530		
	6:00	103.21	74.62	HI	15.75	18.50	12.9	13.1	2.195	2.069	1.987	1.974	2.063	1.844	1.864	1.779	1.807	1.845	1.813	1.983	1.933	2.004	2.086	2.387	2.512		.99 M	6:13(10cc)
	7:00	103.88	74.75	HI	15.94	18.98	13.1	13.4	2.233	2.120	2.000	2.017	2.078	1.884	1.866	1.805	1.829	1.861	1.833	2.061	2.011	2.127	2.343	2.483	2.550	550		
	8:00	104.55	75.04	HI	15.68	18.62	13.1	13.6	2.195	2.085	1.991	1.984	2.004	1.806	1.831	1.789	1.812	1.866	1.847	2.095	2.048	2.156	2.372	2.504	2.577	420		
	9:00	105.17	75.28	HI	15.72	18.63	13.1	13.5	2.242	2.116	1.984	1.976	1.995	1.809	1.825	1.781	1.802	1.854	1.837	2.072	2.026	2.134	2.308	2.437	2.495	460		
	10:00	105.87	75.63	HI	15.70	18.41	13.1	13.5	2.246	2.128	2.011	1.964	1.952	1.804	1.829	1.784	1.790	1.862	1837	2.028	1.995	2.095	2.176	2.311	2.401	450		
	11:00	106.55	75.82	HI	15.62	18.87	13.1	13.5	2.247	2.089	1.975	1.922	1.977	1.820	1.791	1.757	1.777	1.825	1.805	1.993	1.967	2.142	2.342	2.505	2.602	420		
	12:00	107.30	76.13	Lo	12.22	17.97	4.0	3.8	2.232	2.067	1.988	1.945	1.962	1.835	1.813	1.780	1.781	1.843	1.821	2.026	2.003	2.118	2.257	2.341	2.372	450		
	1:00	107.94	76.30	Lo	11.58	14.83	4.0	3.8	1.837	1.755	1.687	1.600	1.454	.907	1.408	.991	1.505	1.549	1.491	1.694	1.674	1.732	1.757	1.788	1.805	170		
	2:00	108.45	76.52	Lo	11.57	14.83	4.0	3.8	2.193	2.101	2.007	1.991	2.051	1.935	1.861	1.838	1.808	1.864	1.838	2.049	2.008	2.073	2.192	2.262	2.336	440		
	3:00	108.96	76.86	Lo	13.09	15.15	4.3	4.4	2.181	2.054	1.992	1.966	2.045	1.922	1.835	1.802	1.794	1.845	1.822	2.005	1.981	2.095	2.222	2.338	2.394	490		
	4:00	109.[illegible]	77.16	HI	1603	18.52	12.9	13.6	2.207	2.103	1.997	1.995	2.096	1.931	1.862	1.829	1.816	1.861	1.821	1.997	1.957	2.055	2.179	2.352	2.502	520		

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TEST NO. 3 — MODULE STATUS — PAGE 2 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	2B	7B	6B	5B	4B	3B	2B	1B	EQUILIBRIUM POINT	NEMA COND. *	
11-11	5:00	10.02	77.54	Hi	16.2	15.39	13.0	13.1	2.154	2.106	2.017	2.026	2.136	2.000	1.913	1.957	1.853	1.871	1.936	2.047	1.957	2.050	2.157	2.378	2.366	550		
	6:00	10:26	77:76	Hi	16.18	18.34	13.1	13.3	2.145	2.037	2.006	2.030	2.146	1.999	1.917	1.959	1.860	1.881	1.945	2.043	1.919	2.041	2.138	2.270	2.343	580		
	7:00	10:62	78:04	Hi	16.25	18.65	13.1	13.3	2.230	2.104	2.002	2.036	2.148	1.984	1.916	1.962	1.856	1.870	1.940	2.043	1.928	2.070	2.218	2.435	2.565	570		
	8:00	10:96	79:39	Hi	16.09	18.52	13.1	13.3	2.225	2.095	1.998	2.020	2.124	1.955	1.880	1.932	1.834	1.867	1.935	2.049	2.007	2.085	2.190	2.361	2.414	520		
	9:00	~~13:00~~ 11:51	78.61	Lo	13.23	15.21	4.4	4.5	1.316	1.743	1.637	1.644	1.583	1.585	1.587	1.559	1.541	1.600	1.928	2.004	1.943	2.08		2.221	2.214	230/470		
	10:00	12:14	79.30	Hi	16.16	19.51	13.2	13.4	2.233	2.140	2.033	2.045	2.108	1.974	1.890	1.931	1.827	1.872	1.931	2.031	1.988	2.085		2.315	2.362	180/460		
	11:00	12:67	79.78	Hi	16.32	19.40	13.5	13.7	2.326	2.235	2.048	1.969	2.030	1.930	1.869	1.817	1.800	1.846	1.910	1.689	1.692	1.734	1.791	1.912	2.000	160/440		
11-12	12:00	13.34	79.55	Hi	16.27	19.00	13.4	13.6	2.392	2.202	2.015	1.964	2.062	1.950	1.849	1.817	1.820	1.843	1.814	2.040	2.022	2.312	2.312	2.540	2.680	410		
	1:00	13.83	79.83	LO	11.87	14.33	4.6	4.6	1.855	2.080	1.988	2.073	2.100	1.991	1.856	1.852	1.844	1.846	1.822	1.937	1.962	2.100	2.214	2.361	2.440	420	2.17 M	(1.33 10cc)
	2:00	14:53	80.04	LO	13.17	16.19	4.5	4.5	1.843	1.720	1.664	1.625	1.620	1.591	1.567	1.565	1.574	1.580	1.550	1.659	1.653	1.737	1.760	1.820	1.845	220		
	3:00	15:04	80.26	Hi	16.49	19.24	4.4	4.5	1.859	1.746	1.699	1.663	1.707	1.670	1.613	1.597	1.617	1.621	1.577	1.663	1.652	1.735	1.752	1.810	1.850	380		
	4:00	15:60	80.61	HI	16.47	18.97	13.3	13.4	2.348	1.769	1.721	1.682	1.780	1.702	1.639	1.609	1.632	1.618	1.586	1.671	1.654	1.718	1.738	1.805	1.863	480	.76M	(4.53 10cc)
	5:00	16.34	80.97	HI	16.53	18.74	13.2	13.3	2.271	2.095	2.061	2.072	2.157	2.055	1.917	1.889	1.937	1.859	1.820	1.973	1.673	1.727	1.753	1.868	1.887	570		
	6:00	16.85	81.20	HI	16.52	18.78	13.3	13.4	2.223	2.087	2.049	2.079	2.165	2.080	1.938	1.896	1.941	1.873	1.891	2.039	1.978	2.091	2.321	2.446	2.542	610		
	7:00	17.51	81.55	LO	13.88	15.45	4.2	4.3	1.813	1.726	1.705	1.695	1.857	1.747	1.657	1.626	1.653	1.632	1.602	1.671	1.651	1.711	1.729	1.803	1.837	560		
	8:00	18.19	81.94	Hi	16.70	19.01	13.5	13.5	1.849	1.752	1.709	1.689	1.761	1.703	1.645	1.614	1.644	1.619	1.587	1.678	1.667	1.721	1.743	1.809	1.845	420		
	9:00	18.48	82.24	Hi	16.58	16.76	13.4	13.4	2.273	2.109	2.056	2.113	2.189	2.033	1.924	1.879	1.917	1.877	1.834	2.012	1.976	2.078	2.212	2.403	2.530	520		
	10:00	19:05	82.65	Hi	16.46	18.71	13.3	13.5	2.231	2.122	2.038	2.064	2.162	2.018	1.915	1.858	1.884	1.880	1.837	2.021	1.931	2.093	2.211	2.375	2.432	230/470		
	11:00	19.38	83.09	Hi	16.43	18.80	13.4	13.5	2.326	2.147	2.016	2.048	2.134	1.971	1.906	1.858	1.879	1.864	1.824	1.703	1.668	1.731	1.768	2.319	2.453	400		
	12:00	20.05	83.26	Lo	12.18	14.92	13.4	13.5	1.890	1.761	1.679	1.512	1.264	.942	1.471	1.112	1.231	1.434	1.408	1.674	1.658	1.733	1.762	1.830	1.883	150		
	1:00	20.94	83.60	Lo	11.84	14.63	4.6	4.4	1.893	1.776	1.698	1.591	1.083	.892	1.492	1.121	1.175	1.408	1.371	1.665	1.654	1.725	1.761	1.833	1.870	130		
	2:30	21.15	84.02	Lo	12.14	14.91	4.5	4.3	1.864	1.734	1.673	1.621	1.585	1.036	1.494	1.189	1.529	1.558	1.471	1.649	1.643	1.719	1.753	1.827	1.857	170		
	3:00	21.49	84.22	Hi	15.73	17.76	12.9	13.2	2.258	2.034	1.946	1.948	2.084	1.991	1.847	1.805	1.586	1.839	1.793	1.913	1.687	2.031	2.181	2.444	2.576	470		
	4:00	22.25	84.48	Hi	16.33	19.14	13.2	13.4	2.390	2.081	1.994	1.988	2.110	2.008	1.887	1.851	1.955	1.853	1.803	1.964	1.921	2.075	2.347	2.516	2.714	535		
	5:00	22.82	84.74	Hi	16.64	19.47	13.4	13.4	2.405	2.117	2.036	2.022	2.124	2.062	1.935	1.867	1.914	1.849	1.809	1.988	1.915	2.036	2.282	2.502	2.687	570		
	7:00	24.01	85.32	Lo	13.65	15.38	4.2	4.3	1.830	1.750	1.711	1.617	1.775	1.638	1.633	1.616	1.659	1.639	1.599	1.689	1.676	1.733	1.738	1.796	1.844	380/650		
	8:00	24.71	85.66	Hi	16.59	19.07	13.1	13.2	2.371	2.148	2.032	2.077	2.152	2.047	1.934	1.878	1.983	1.877	1.835	2.048	1.993	2.105	2.339	2.547	1.870	320/520		
	9:00	25.01	85.83	Hi	16.64	19.42	13.3	13.5	2.392	2.181	2.031	2.077	2.142	2.027	1.933	1.887	1.954	1.881	1.855	2.092	2.032	2.141	2.369	2.584	2.671	230/470		
	10:00	25.48	85.90	Lo	13.34	14.77	4.5	4.4	1.852	1.759	1.693	1.623	1.593	1.331	1.425	.944	1.328	1.549	1.454	1.685	1.673	1.734	1.750	1.810	1.845	130/460		
	11:00	25.51	86.30	Hi	16.71	19.15	13.3	13.4	2.372	2.175	2.077	2.067	2.147	2.093	1.961	1.935	1.958	1.902	1.841	2.068	2.025	2.138	2.324	2.530	2.635	160/450		
11-13	12:00	26.14	86.58	LO	11.74	14.69	4.6	13.2	2.347	2.131	2.051	2.042	2.111	2.021	1.929	1.898	1.900	2003	1.881	[illegible]					430		2.75 M	(12.00 10cc)
	1:00	26.84	86.77	HI	16.74	19.54	4.3	13.6	1.878	1.761	1.694	1.642	1.630	1.523	1.565	1.544	1.584	1.593	1.472	1.669	1.654	1.723	1.747	1.818	1.865	260		

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* EVERY 4 HOURS

TEST NO. 3

MODULE STATUS

PAGE 3 OF ___

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	(3A)	(4A)	(5A)	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC.*
11-13	2:00	27.23	87.04	Lo	15.81	15.50	4.3	4.4	1.837	1.750	1.717	1.668	1.683	1.687	1.624	1.601	1.639	1.611	1.576	1.665	1.647	1.715	1.730	1.791	1.842	350	
	3:00	27.62	87.37	Hi	16.64	19.11	13.1	13.3	1.832	1.762	1.707	1.695	1.804	1.751	1.648	1.624	1.662	1.622	1.584	1.659	1.638	1.694	1.699	1.786	1.838	470	
	4:00	28.15	87.57	Hi	16.76	19.03	13.3	13.4	2.363	2.121	2.081	2.102	2.150	2.094	1.966	1.909	2.021	1.884	1.831	2.022	1.939	2.075	2.342	2.476	2.610	590	.83M (4.10 10cc)
	5:00	28.59	87.84	Hi	16.95	19.30	13.5	13.6	1.876	1.762	1.727	1.710	1.801	1.743	1.654	1.602	1.665	1.625	1.590	1.675	1.652	1.720	1.736	1.803	1.857	470	
	6:00	29.07	88.10	Hi	16.42	18.93	15.2	13.4	2.332	2.095	2.023	2.052	2.114	2.034	1.927	1.920	2.011	1.869	1.826	1.986	1.938	2.103	2.364	2.524	2.630	510	
	7:00	129.68	88.40	Lo	15.98	15.10	4.3	4.4	2.271	2.060	2.015	2.075	2.143	1.991	1.885	1.877	1.935	1.858	1.811	1.975	1.945	2.110	2.301	2.435	2.462	490	
	8:00	130.20	88.61	Lo	11.79	14.31	4.4	4.4	1.848	1.697	1.668	1.637	1.588	1.059	1.436	1.009	1.249	1.439	1.467	1.615	1.606	1.696	1.723	1.801	2.279	350	
	9:00	130.77	88.74	Hi	12.04	14.74	13.3	13.6	1.881	1.731	1.661	1.590	1.509	1.083	1.408	1.036	1.420	1.562	1.457	1.636	1.625	1.718	1.740	1.801	1.852	140	
	10:00	131.46	88.87	Hi	16.57	19.48	13.3	13.6	1.895	1.762	1.698	1.475	1.447	.980	1.476	1.312	1.402	1.498	1.412	1.648	1.636	1.719	1.741	1.818	1.869	190	
	11:00	132.01	89.19	Lo	11.57	14.42	4.6	4.4	2.311	2.092	2.003	2.121	2.096	2.003	1.908	1.881	1.931	1.821	1.788	1.964	1.942	2.101	2.238	2.431	2.497	450	
	12:00	132.61	89.45	Hi	16.88	19.67	13.5	13.6	2.548	2.191	2.044	2.055	2.124	2.031	1.927	1.905	1.993	1.864	1.821	2.031	1.974	2.144	1.875	1.904	1.965	380	
	1:00	133.23	89.71	Hi	16.74	18.86	13.5	13.5	2.386	2.131	2.062	2.086	[illegible]	2.042	1.959	1.941	2.007	1.871	1.811	2.001	1.950	2.095	2.309	2.501	2.622	470	
	2:00	133.84	89.97	Hi	16.31	19.05	13.4	13.5	2.431	2.069	1.981	1.961	2.072	1.977	1.870	1.898	1.976	1.821	1.724	1.771	1.929	2.055	2.252	2.522	2.699	440	

* [illegible]

TEST NO. 4 SYSTEM STATUS PAGE 1 OF ___

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) MOD	PT	PO_2	CAL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N_2H_4	META	N_2	BUB. EP.	GAS ANALYSIS N_2-O_2	CABIN	H_2	O_2 METER
12-7	[illegible]	0	1463	28.7	20.8			36	4.7	116	1.9	5.9	50	3.8	.8	0	1.4	0	100				
	[illegible]	2	1659	28.7	21.0			36	4.4	131	1.9	5.9	42	3.0	.8	0	2.0	0	120				
	7:45	2:15	Start N_2H_4 PO_2 = 140 chart 137 recorder 137 control																				
			PO_2 control cal set to 150 N_2H_4 flow = 9.0 Out: 3.31 = 2140 OK																				
			Note prior to N_2H_4 start Main H_2 set .224.74%																				
	8:20		Return PO_2 control to = PO_2 Data Signal 151																				
	8:35							37	4.3	153	1.9	5.9	41							2160 OK			
	9:00		Changed Servo gain N_2H_4 recorder																				
	9:05		Removed 10 cc KOH (56) 3.74 turns 8.5																				
	9:10		N_2 Sample Cathode Hi current 5.5% N_2 (1.62M)																				
	9:30	4	1866	28.5	21.0	28.5	9.0	36	4.3	160	1.9	5.9	41	3.5	.8	8.5	3.6	12.2	130	2616 (2140 cc/m)			
	11:15		N_2 Sample Cathode Hi current 7.1 % N_2 (2.2 M) Press = 445																				
	11:30	6	2064	28.7	21.8	28.6	9.0	36	4.3	159	1.9	5.9	43	4.0	.8	[illegible]	3.6	12.5	143	2624 2140 cc/m			
12-8	[illegible]:30	8	2121	[illegible]		28.5	9.5	31	4.3	156	1.9	5.9	42.5	3.3	.8	8.5	3.5	12.3	160	[illegible]	2110 cc/min		
	3:18		H_2O Collection Res. 260 cc, Bring up to 70 cc																70				
	3:32	10	2412			28.5	9.5	34	4.3	148	1.9	5.9	42	3.8	.8	8.5	3.5	12.5	75	2110 cc/m			
	4:25		Removed N_2H_4 & weigh; total wt. = 1572 g − 208 gm. = 1364 gm. 1939−1364 = 575 gm./1st cycle																				
	[illegible]	12	2285 − 208 = [illegible] gm 1364 [illegible].5 put back																				
	5:32	12	2604			28.5	9.5	32	4.3	146	1.9	5.9	41	3.3	—	—	3.5	12.5	85	2100 cc/m			
	7:35	14	2935			28.3	9.4	29	4.4	154	1.9	5.9	45	3.3	.78	~9.0	3.5	12.45	95	2090 cc/min			2652 ft³
	8:30	15	−13	28.5	21.8	[illegible]		33	4.3	156	1.9	5.9	44	3.2	.78	~8.6	3.5	12.4	95	2090 cc/min			2656
	9:10		Reset N_2H_4 flow control valve to 3.93 turns																				
	9:30	16	131	28.5	21.8			35	4.3	156	1.9	5.9	44	3.2	.75	bubble	3.4	12.35	100	2080 cc/min			2660
	9:45		Adjusted N_2 makeup to 12.5 ss																				
	10:30	17	239			28.5	9.3	39	4.3	153	1.9	5.9	43	3.0	.75	~8.9 bubble	3.5	12.5	100	2080 cc/min			2664
noon	12:00		Removed N_2H_4 & weigh 2nd cycle N_2H_4 351.4 gms																				
	1:30	20	524	28.5	21.4			39	4.3	143	1.9	5.9	42	3.0	.75	-0-	3.5	12.5	100	2080 cc/min			2678
	3:00		coolant cycled off for first time in a long time																				
	4:30	23	771			28.4	9.5	37	4.3	153	1.9	5.9	45	3.0	.75	9.5 bubble	3.5	12.45	100	2080 cc/min			2691
	5:[illegible]	24	Removed 10 cc KOH to [illegible] [illegible]																				

TEST NO. 4 — SYSTEM STATUS — PAGE 3 OF —

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) MOD	PT	P_{O_2}	CAL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N_2H_4	META	N_2	BUB. SEP.	GAS ANALYSIS N_2-O_2	CABIN	H_2	
pm 12-8	6:35	25+	968	28.6	21.5	28.7	9.2	41	43	154	1.9	5.7	44	3.8	.8	8.5 gas	3.6	12.5	100	2700	2760 cc/min		WET TEST O2
	8:40	27+	1184			28.6	9.3	31	43	151	1.9	5.5	45	4.6	.8	9.0	3.6	12.4	100	2709	2080 cc/min		
	10:00	Adjusted high current on A & B down to ~ 13.5 Amps.																					
	10:35	29th Changed meta & N_2 makeup to 2.055 and 4.855 respectively																	(855cc/min meta)				
	10:45		1383															10.0		2717.5			
	11:00	Note Last cycle 440.7 cc N_2H_4 consumed																					
	11:10	29?	N_2 to 5.7 (4th)	Qmet = 2.1 (945)				4 man size															
	11:30	30	1440			28.3	9.1	35	42	147	1.9	5.9	50	5.2	—	off	2.1	5.8	—				
	11:45		flow check	Qmet = 954 cc/min (Level)																			
am 12-9	1:34	32+	1609			28.5	9.5	41	43	157	1.9	5.9	44.5	5.3	—	gas 8.0	2.0	5.7		944 cc/min			
	2:50			Remove 10cc electrolyte																			
	3:30	34	1624			28.5	9.5	43	43	163	1.9	5.9	43.5	5.5	—	8.5 gas	2.0	5.7		943 cc/min			
	5:33	36+	1709			28.5	9.3	43.5	43	162	1.9	5.9	44.5	5.6	—	8.0 gas	2.0	5.7		940 cc/min			
	7:45		2067			28.5	9.5	46	4.3	160	1.9	5.9	50	5.6		8.5 gas	2.1	5.7		935cc/min adj to 946			Remove 10cc 8:00am
	9:10	adjust meta to 990 cc/min (Current not cycling)																					
	9:30	40																		999cc/min			Remove 10cc 9:30 am
	9:40		2236			28.5	9.5	42	4.4	160	1.9	5.9	49	5.8	.8	8.4	2.1	5.7	100	955cc/min	(?) 2749		
	10:30	41	2307			28.5	9.5	38	4.3	160	1.9	5.9	48	6.3	-	8.8 gas	2.1	5.7	100	955cc/min	2741		10cc 10:15
	1:30	44	2541			28.5	9.5	37	4.4	157	1.9	5.9	50	5.8	-	8.6 gas	2.1	5.7	100	950cc/min	2751		
	2:30	45	2632			28.5	9.5	45	4.3	156	1.9	5.9	51	6.5	.8	8.6 gas	2.1	5.7	100		2759		20cc 10:30
	2:45	changed meta & N_2 makeup to 5-man rate																		1150cc/min			
	3:45																			1148cc/min			30cc 11:30
	4:00	Adjusted N_2 makeup to 6.655																		1070cc/min			30cc 1:30
	4:35	47+	2447			28.5	9.4	45	4.4	155	1.9	5.9	49	6.0	-	8.5 gas	2.3	6.6	100	1055cc/min	2754		10cc 3:30
	4:55	Changed meta & N_2 makeup to 6-man rate															2.5	7.5		1285cc/min			20cc 5:30
	6:50	Drain N_2H_4 & recharge 1298.9 used																		@ 7:35 31			
	7:10	7:35 Act start	set @ 10 min level	Meta = 1870 (3.35)										N_2 = 1265 cm				(11.055)	P_{meta} = 31	@ 720 725	1830 720 10 in	1900	
	7:40	50+	0111			28.5	9.1	31	4.3	154	1.9	6.0	47	6.7	—	9.0	3.3	11.0		2763	a 1900 cc/min		
	9:30	52	0309	27?	22	28.7	9.1	37	4.3	155	1.9	5.8	47	7.2	.8	9.5	3.3	11.0	-	2771			
	11:30	54	0549	28?	28	28.9 ~~28~~		34	4.3	152	1.9	5.5	46	6.0	.8	9.0	3.3	11.0	—	2779			
12-10	1:16					ADJUST META FLOW TO 3.6 SS = 2147 cc/min (12 man rate)																	

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TEST NO. 4 SYSTEM STATUS PAGE 3 OF __

DATE	TIME	ELAPSED TIME (HRS)	HYDROGEN OUTPUT METER	POWER INPUT HIGH VOLTS	HIGH AMPS	LOW VOLTS	LOW AMPS	PRESSURE (PSIG) MOD	PT	P_{O_2}	CAL	N_2H_4	COOLANT TEMP (°F)	FLOW RATE KOH	COOLANT	N_2H_4	META	N_2	BUB. SEP.	GAS ANALYSIS N_2-O_2	CABIN	H_2
12-10	1:32	0719,	57	28.5	22.5			32	4.5	146	1.9	5.9	43°	7.0	.8	—	3.6	11.0				
	1:52		drain 1362 gm. from N_2H_4 tank → ΔM = 421.8 gm.																			
	3:30	0910	59	[illegible]		28.3	9.3	31	4.5	147	1.9	5.9	43.5	6.2	—	—	3.6	12.5		2145 cc/min		
	5:30	1000	61			28.3	9.3	36	4.5	154	1.9	5.9		6.8	—	8.5 gas	3.6	12.5		2140 cc/min		
	7:30	1321	63			28.3	9.3	38	4.5	151	1.9	5.9	44	6.7	.8	gas	3.6	12.5		2140 cc/m		
	8:00	Adjust high current A&B to 13.5 Amps (both were high)																				
	9:15	Adjust high & low currents to 7.6 Amps; high to 12.8 amps																				
	9:30	65	1628	26.5	22.5			37	4.6	143	1.9	5.9	47	6.0	-0-	-0-	3.5	12.5		2090 cc/min		
	10:30	66 Refilled N_2H_4 tank						ΔN_2H_4 this cycle 320 gms														
	11:30	67	1815	28.5	21.8			41	4.6	146	1.9	6.0	49	6.3	-0-	-0-	3.5	12.45		2070 cc/min		
	1:30	69	2051			28.5	10.5	36	4.6	154	1.9	5.9	48	6.5	.8	10 gas	3.5	12.4		2060 cc/min		
	3:45		2244	28.5	20.4			40	4.6	147	1.9	5.9	46	5.5	.8	9.5 gas	3.5	12.4		2050 cc/min		
	4:30	72 Refilled N_2H_4 tank						ΔN_2H_4 last cycle 289.1 gms									~~3.6~~	~~12.5~~				
	6:30	73	2412	28.8	21.8	28.4	10.5	32	4.5	143	1.9	5.8	44	6.0	.7	0	3.6	12.5		2060 cc/min		
	7:30	75	2587	?		28.6	10.2	36	4.6	146	1.9	5.8	50	5.8	"	"	3.6	12.5				
	8:35		Removed 75 cc to lower P mod																			
	8:30	76	N_2H_4 on																			
	8:35		shut off N_2H_4 & water in water valve leak — insert toggle																			
	9:00		toggle in & checked - N_2H_4 back on @ 3 turns																			
	9:10		Qmt dropped to 2020 raise 2120 ok															~~3.6~~	~~12.5~~				
	9:30	77	2736			28.5	10.5	45	4.7	154	1.9	5.9	48	2.5	.7	6.2	3.6	12.5				
	10:00		Return N_2H_4 feed to original setting										Pmod = 41	N_2H_4 8.4								
	11:30	79	2727	28.7	20.8			41	4.6	160	1.9	5.9	49	5.5	—	8.3	3.6	12.5	—	2120 cc/min		H_2O leak .57/min 10 cm travel
	1:30	81	0115	28.6	21.2			38	4.6	161	1.9	5.4	43	5.5	.9	8.3	3.6	12.4		2120 cc/min		
	3:32	83	0307	28.6	19.5			39	4.6	153	1.9	5.9	43.5	6.5	.7	8.3	3.6	12.5		2120 cc/m		
	4:31	84	0501	28.7	19.3			32.5	4.5	143	1.9	5.9	42	3.0	.7	—	3.6	12.5		2100 cc/min		
	5:45	85		1207 gm. N_2H_4 removed → 513 gm/cycle													~~3.6~~	~~12.6~~				
	7:34	87+	0721	28.7	19.3			30.0	4.5	146	1.9	5.9	41.5	2.5	.7	—	3.6	12.6		2100 cc/m		
	8:00	system shut down manually																				
				Drained 1870 cc from H_2O Tank																		

TEST NO. 4 — MODULE STATUS — PAGE 1 OF —

	DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC.*	
MON	12-7	5:40	34.26	93.50	Hi	15.38	17.60	13.5	33.5	2.061	1.962	1.925	1.911	1.979	1.862	1.958	1.828	1.899	1.872	1.848	1.985	1.935	1.991	2.023	2.059	2.124	✓		
		6:30	34.26	93.50	Hi	15.57	17.79	13.4	33.5	2.121	1.956	1.943	1.943	2.058	1.861	1.861	1.825	1.841	1.852	1.842	1.955	1.906	2.001	2.003	2.034	2.182	~~FOR~~		
		7:30	—	—	Hi	15.78	18.04	13.5	33.6	2.151	2.019	1.969	1.986	2.033	1.931	1.871	1.925	1.947	1.904	1.850	1.982	1.930	2.027	2.035	2.141	2.243	600		
		8:30			Hi	15.71	17.81	13.5	33.6	2.133	2.002	1.9	1.967	2.015	1.852	1.863	1.878	1.837	1.817	1.841	1.968	1.918	2.002	2.019	2.137	2.260	560/520		
		9:30	—	—	Lo	13.95	15.98	6.85	6.85	1.910	1.804	1.768	1.784	1.753	1.634	1.677	1.632	1.643	1.684	1.645	1.741	1.716	1.808	1.819	1.911	1.961	480/390		
		9:30			Hi	15.64	17.96	33.6	13.7	2.171	2.026	1.970	1.940	2.000	1.873	1.851	1.790	1.811	1.864	1.829	1.948	1.906	2.03X	2.065	2.208	2.324			
		10:30	36:41	94:55	Lo	13.87	15.95	6.90	6.90	1.910	1.796	1.755	1.717	1.727	1.672	1.667	1.628	1.640	1.674	1.642	1.741	1.721	1.809	1.823	1.914	1.980	460/330		
		11:30	36:15	94:17	Hi	15.59	17.25	13.8	13.9	2263	2.047	1.957	1.931	1.968	1.824	1.806	1.773	1.783	1.651	1.644	1.755	1.729	1.824	1.842	1.940	2.035	440/300		
TUES		12:30	36:99	95:38	LO	13.66	15.78	7.0	7.0	1.904	1.765	1.736	1.708	1.700	1.635	1.617	1.585	1.607	1.625	1.603	1.919	1.891	2.022	2.060	2.203	2.327			
		1:30	37:55	95:56	Hi	15.36	18.01	13.8	13.8	2.244	2.021	1.925	1.904	1.930	1.804	1.780	1.748	1.759	1.821	1.788	1.933	1.908	2030	2.071	2.248	2.378	380		
		2:35	37:99	96:04	Hi	15.60	18.39	14.0	14.1	2.296	2.074	1.955	1.921	1.928	1.640	1.621	1.592	1.608	1.661	1.634	1.751	1.724	1.821	1.853	1.954	2.035	275		10 cc
		3:30	38:51	96:41	LO	13.78	16.05	6.8	6.8	1.957	1.809	1.748	1.702	1.688	1.628	1.612	1.593	1.603	1.652	1.619	1.709	1.685	1.803	1.842	1.948	2.021	230	2.58 M	4:00 AM
		4:32	38.73	96.88	Hi	15.23	18.13	13.6	13.6	2.163	2.001	1.935	1.881	1.912	1.794	1.772	1.738	1.755	1.805	1.773	1.882	1.864	2.017	2.111	2.351	2.129	390		
		5:30	39.08	97.26	LO	13.91	16.18	6.7	6.8	1.896	1.806	1.767	1.733	1.747	1.685	1.657	1.637	1.643	1.689	1.655	1.772	1.752	1.840	1.873	1.941	1.995	400		
		6:30	39.51	97.82	Hi	15.90	18.43	14.6	14.7	2.196	2.108	2.010	1.979	2.077	1.877	1.853	1.813	1.834	1.884	1.841	1.995	1.956	2.058	2.131	2.365	2.515	515	.87 M	10 cc 7:00 AM
		7:30	39.97	98.30	HI	15.89	18.30	13.6	13.9	2.196	2.095	2015	1.988	2.097	1884	1.862	1.820	1.838	1.890	1857	2.007	1.959	2.064	2117	2.315	2.417	530		
		8:30	40.41	98.66	LO	14.07	16.08	6.7	6.7	1.933	1.831	1.784	1.731	1.768	1.687	1.667	1637	1660	1678	1.644	1.729	1.760	1.795	1.835	1.931	2.093	390		
		9:30	40.87	99.19	HI	15.71	18.31	13.5	13.6	2.240	2.085	1.993	1.940	2.039	1.849	1.819	1.782	1.800	1.854	1.824	1.961	1.938	2.060	2.114	2.364	2.519	450		
		10:30	41.14	99.55	HI	15.71	18.59	13.6	13.7	2.304	2.107	1.973	1.921	1.993	1819	1.802	1.775	1789	1.845	1.814	1.750	1.727	1826	1.960	1.988	2102	340	2.60	10 cc 12.00 noon
		1:30	42.20	100.82	LO	13.81	15.81	6.7	6.7	1.883	1.792	1.753	1.714	1.743	1.665	1.641	1.621	1.635	1.668	1.627	1.695	1.671	1.766	1.799	1.920	2.018	360		
		3:45	42.92	102.03																								1.05	10 cc 3:42
		4:30	43.07	102.43	HI	16.12	18.76	13.7	13.7	2.245	2.163	2033	1.977	2.121	1.884	1.869	1.834	1.857	1857	1.844	1.958	1.740	1821	1.851	1.957	2.113	510		
		5:30	43.47	02.96	LO	14.02	16.03	6.85	6.90	1.912	1.823	1.750	1.722	1.765	1.631	1.667	1.650	1.662	1.633	1.652	1.73X	1.711	1.802	1.828	1.924	2.004	400/490		
		6:40	43.95	03.53	Hi	15.85	18.48	13.4	13.8	2.247	2.108	2.006	1.925	2.062	1.782	1.660	1.637	1.651	1677	1.643	1.717	1.698	1.791	1825	1.945	2.042	450/330		
		7:30	44.29	03.78	Hi	15.58	18.06	13.7	13.8	2.197	2.060	1981	1.926	2.024	1833	1804	1770	1792	1827	1.794	1.902	1.859	2.009	2.035	2.251	2.359	420/290		
		8:30	44.67	04.25	Lo	14.01	16.24	6.90	6.95	1.946	1.858	1.766	1.719	1.758	1.679	1.667	1.652	1.649	1.709	1.673	1.757	1.774	1.835	1.863	1.930	1.972	456/290		
	29	9:30	44.93	04.86	Lo	14.08	16.24	6.90	6.95	1.908	1.863	1.775	1.726	1.781	1.694	1.683	1.662	1.681	1.719	1.682	1.814	1.783	1.831	1.850	1.899	1.928	420/280		
	30	11:30	45.17	06.23	Lo	14.19	16.11	6.9	6.9	1.877	1.847	1.774	1.732	1.822	1.729	1.718	1.692	1.693	1.738	1.686	1.801	1.772	1.807	1.821	1.881	1.913	380		
JED		12:30	45.17	07.30	LO	14.24	16.12	6.9	7.8	1.862	1.842	1.785	1.744	1.866	1.732	1.722	1.695	1.701	1.737	1.688	1.809	1.773	1.805	1.818	1.869	1.898	415	~~1.58~~ 1.594	10 cc 12:15
		1:30	46.24	07:96	LO	14.15	15.99	6.7	6.8	1.859	1.829	1.772	1.737	1.837	1.732	1.723	1.690	1.693	1.736	1.684	1.802	1.770	1.800	1.818	1.876	1.917	365		remove
		2:30	45.20	08:56	LO	14.12	16.03	6.7	6.8	1.841	1.824	1.772	1.729	1.806	1.725	1.721	1.685	1.697	1.726	1.678	1.799	1.764	1.787	1.804	1.857	1.904	330		10 cc 2:40
		3:30	46.37	09.49	LO	14.09	16.08	6.7	6.8	1.857	1.835	1.762	1.718	1.782	1.711	1.702	1.673	1.674	1.717	1.672	1.803	1.768	1.798	1.814	1.875	1.927	285		3:05 - 10 cc

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TEST NO. 4

MODULE STATUS

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC. *	
12-35	4:30	45:37	10:49	LO	14.07	16.14	6.7	6.8	1.885	1.851	1.764	1.722	1.777	1.712	1.701	1.670	1.674	1.722	1.676	1.810	1.780	1.815	1.829	1.892	1.925	290		10cc 3:45 AM
36	5:30	45:37	11:49	LO	14.03	16.05	6.7	6.8	1.855	1.833	1.764	1.719	1.771	1.710	1.703	1.668	1.672	1.718	1.673	1.801	1.766	1.788	1.805	1.862	1.898	270		10cc 4:55 AM
37	6:30	45:37	12:49	LO	14.08	16.08	6.7	6.8	1.865	1.843	1.766	1.717	1.777	1.717	1.714	1.673	1.677	1.722	1.677	1.803	1.770	1.793	1.812	1.873	1.919	265		5:45 10cc
38+	7:40	45:37	13:46	LO	14.02	16.01	6.7	6.8	1.868	1.837	1.761	1.711	1.775	1.716	1.707	1.671	1.676	1.721	1.675	1.802	1.767	1.797	1.819	1.885	1.933	250		6:45 10cc
40+29	9:45	45:57	15:55	LO	14.04	16.05	6.8	6.8	1.875	1.846	1.757	1.710	1.773	1.713	1.703	1.669	1.670	1.721	1.673	1.802	1.771	1.802	1.828	1.894	1.948	240	2.75M	8:00 – 10cc
41	10:30	45:59	16:27	HI	16.06	18.91	13.4	13.6	2.197	2.230	1.997	1.940	2.045	1.919	1.888	1.850	1.857	1.927	1.887	2.118	2.044	2.085	2.180	2.246	2.297	380	2.78M	11:30
44	1:30	45:70	16:27	LO	14.06	16.18	6.7	6.8	1.902	1.868	1.763	1.722	1.775	1.706	1.669	1.661	1.668	1.723	1.681	1.818	1.784	1.818	1.845	1.921	1.967	240		
45	2:30	45:77	16:91	LO	14.13	16.17	6.7	6.8	1.871	1.868	1.774	1.720	1.788	1.721	1.712	1.677	1.686	1.735	1.678	1.814	1.781	1.802	1.825	1.894	1.932	240		
47	4:30	45:99	17.69	LO	14.08	16.19	6.6	6.7	1.862	1.863	1.765	1.711	1.786	1.712	1.784	1.671	1.687	1.730	1.672	1.813	1.774	1.881	1.843	1.876	1.926	220		
49+	6:35	46.44	19.41	Hi	16.62	19.75	13.8	14.0	2.375	2.418	2.029	1.954	2.155	1.951	1.918	1.861	1.866	1.957	1.908	2.261	2.119	2.169	2.455	2.601	2.715	390/220		
50+	7:35	46.77	19.94	Hi	16.77	19.82	13.8	14.0	2.457	2.433	2.044	1.973	2.185	1.952	1.913	1.871	1.891	1.923	1.917	2.270	2.135	2.187	2.481	2.593	2.703	270/410		
51	8:30	47.05	19.19	Hi	16.93	19.97	14.0	14.1	2.524	2.474	2.058	1.980	2.206	1.958	1.918	1.864	1.870	1.924	1.923	2.234	2.158	2.233	2.496	2.574	2.682	230/390		
	9:30	47.55	19.61	LO	14.11	16.31	6.8	6.9	1.943	1.872	1.766	1.714	1.786	1.709	1.684	1.660	1.659	1.734	1.701	1.825	1.802	1.834	1.857	1.967	1.972	200/370		
	10:30			HI			14.3	14.2																				
	10:30	48.05	19.77	LO	13.92	16.46	6.9	6.9	1.905	1.900	1.757	1.715	1.756	1.663	1.557	1.633	1.649	1.726	1.690	1.820	1.783	1.824	1.870	1.922	1.974	180/360		
	11:30	48.66	20:17	Lo	14.1	16.21	6.9	6.9	1.937	1.862	1.764	1.738	1.80)	1.697	1.676	1.659	1.658	1.722	1.684	1.815	1.786	1.832	1.857	1.905	1.942	160/350		
FLUIDS	12:30	49.24	20:44	LO	14.12	16.19	13.7	14.0	2.250	2.173	2025	2.006	2.183	1.943	1.896	1.857	1.860	1.944	1.910	2.155	2.105	2.154	2.265	2.261	2.313	/340		
2096	1:30	49.94	20:54	Hi	16.01	19.13	13.7	13.9	2.251	2.230	1.964	1.914	2.073	1.850	1.812	1.781	1.784	1.887	1.870	2.155	2.078	2.184	2.372	2.465	2.647	/300	3.28M	10cc 1:25 PM
	2:30	50.61	20.88	Hi	16.54	19.96	13.6	13.7	2.381	2.353	2.075	2.002	2.205	1.952	1.911	1.864	1.883	1.960	1.913	2.236	2.153	2.214	2.388	2.402	2.425	410		
	3:30	50:97	21:05	Hi	17.41	20.24	14.2	14.1	2.648	2537	2.163	2.059	2.275	2.005	1.991	1.894	1.908	1.985	1.930	2.330	2.206	2.299	2.068	Lo 2.077	2.149	440	1.14M	10cc 4:20 PM
2.197	4:30	51:46	21:52	Hi	17.17	19.94	14.0	14.0	2.485	2.425	2.143	2.048	2.252	2.007	1.943	1.898	1.923	1.988	1.935	2.305	2.176	2.250	2.417	2.528	2.633	490		
	5:30	51.87	21:09	Hi	17.13	19.96	14.0	14.0	2.584	2.461	2,101	2.001	2.249	1.984	1.927	1.884	1.898	1.982	1.930	2.292	2.175	2.242	Lo 2.075	2.112	2.185	420		
	6:30	52:31	22:18	Hi	16.95	19.93	13.4	13.6	2.343	2.272	2.047	1.976	2.204	1.954	1.909	1.860	1.877	1.966	1.915	2.197	2.168	2.171	2.358	2.461	2.537	345		
	7:30	52:76	22:59	LO	14.04	16.44	6.6	6.7	1.951	1.876	1.770	1.724	1.787	1.701	1.678	1.666	1.677	1.737	1.694	1.823	1.798	1.828	1.851	1.902	1.938	210		
	9:30	53.51	23:50	HI	16.66	19.46	13.2	13.1	2.481	2.347	2.037	1.974	2.209	1.935	1867	1859	1852	1.998	1.900	2.229	2.127	2.188	2.392	2.531	2.639	380		
	11:30			LO	14.00	16.30	7.2	7.2	1.876	1.853	1.826	1.786	2.021	1.767	1.748	1.721	1.734	1.767	1.718	1.822	1.800	1.815	1.833	1.865	1.891	440		
	1:30	55.25	24.62	HI	16.36	19.05	12.6	12.5	2.267	2.231	2.034	1.961	2.198	1.922	1.885	1.860	1872	1.929	1.884	2.175	2.057	2.098	2.274	2.411	2.498	430		
	3:30	56.04	25.47	LO	14.91	16.52	7.3	7.3	1.952	1.880	1.804	1.749	1.862	1.739	1.731	1.697	1.703	1.747	1.789	1.850	1.823	1.848	1.864	1.917	1.952	250		
	5:30	56.88	26.36	LO	14.62	16.60	7.4	7.4	1.947	1.898	1.808	1.769	1.989	1.765	1.743	1.709	1.712	1.765	1.725	1.862	1.829	1.849	1.871	1.921	1.957	310/410	2.73M	10cc 4:20
	6:30	57.20	26.97	LO	14.61	16.34	7.4	7.4	1.905	1.866	1.825	1.789	2.052	1.776	1.761	1.724	1.735	1.770	1.744	2.051	2.004	2.023	2.066	2.120	2.136	400/460		
	7:30	57.49	27.28	LO	14.62	16.33	7.4	7.4	1.866	1.848	1.823	1.790	2.044	1.775	1.757	1.724	1.743	1.773	1.724	1.836	1.803	1.818	1.831	1.871	1.895	460/440		

* EVERY 4 HOURS

TEST NO. 4 — MODULE STATUS — PAGE 3 OF —

DATE	TIME	HIGH TIMER	LOW TIMER	MODE	MOD VOLTS A	MOD VOLTS B	MOD AMPS A	MOD AMPS B	CELL VOLTAGE 1A	2A	3A	4A	5A	6A	7A	8A	9B	8B	7B	6B	5B	4B	3B	2B	1B	EFFLUENT P_{O_2}	N_2H_4 CONC. *
12-10	8:30 AM	57.80	27.58	Hi	16.62	19.24	13.0	12.9	2.217	2.271	2.049	2.056	2.266	4/1989	1.935	1.876	1.902	1.962	1.902	2.280	2.036	2/63	2.314	2.452	2.542	540 520	
	9:30	58.07	27.99	Lo	14.77	16.53	7.4	7.4	1.908	1.860	1.832	1.856	2.055	1.779	1.758	1.730	1.753	1.783	1.743	1.843	1.819	1.850	1.900	1.930	1.982	500/520	
	10:30	58.64	28.25	Lo	14.80	16.62	7.4	7.4	1.940	1.888	1.807	1.825	2.050	1773	1.750	1.726	1.739	1.785	1.746	1.840	1.818	1.832	1.885	1.904	1.946	490/490	
	11:30	57.30	28.56	Hi	16.79	19.58	13.0	12.9	2.527	2.312	2017	2.002	2210	1.947	1.888	1.854	1.865	1.951	1.908	2.248	2102	2.172	2.360	2.515	2.660	370/440	
	12:30	59.96	28.73	Lo	14.38	16.31	7.3	12.5	2.112	2.050	1.963	1.940	2187	1.916	1873	1.832	1.837	1.917	1.879	2.053	2.030	2039	2.095	2.107	2081	410	
	1:30	60.76	28.82	Hi	16.53	19.91	12.9	12.9	2.565	2.259	1.971	1.921	2163	1.916	1.854	1.831	1.837	1.937	1912	2.242	2.134	2210	2.381	2.528	2.720	365	
	2:30	61.49	29.11	Lo	14.22	16.61	7.3	7.2	1.982	1.868	1.758	1.715	1.793	1.719	1.684	1.675	1.679	1.750	1.722	1.843	1.828	1.849	1.877	1.934	1.980	330	
	3:00			Lo	14.18	16.46	7.3	7.3	1.955	1.862	1.765	1.731	1.806	1.726	1.698	1.681	1.682	1.754	1.721	1.841	1.824	1.843	1.852	2/08	2.157	310	
	4:30	62.81	29.76	Lo	15.60	18.15	12.3	12.4	2.167	2.105	1.946	1.907	2.115	1.988	1.848	1.822	1.819	1.909	1.880	2.095	2.052	2.065	2.131	2.179	2238	345	
	5:30	63.27	30.05	Hi	15.11	18.05	12.3	12.3	2.124	1.983	1.914	1.875	1.950	1.809	1.770	1.744	1.787	1.852	1.826	2.058	2.035	2131	2237	2282	2331	350	3.04 M 10 cc 5:10 AM
	6:30	63.75	30.33	Lo	14.12	16.54	7.2	7.2	1.875	1.802	1.776	1.746	1.851	1.717	1.687	1.672	1.706	1.745	1.721	1.840	1.837	1.867	1.896	2164	2235	390	
	7:30	64.18	30.67	Lo.	14.26	16.34	7.2	7.2	1.925	1.832	1.800	1.768	1.887	1.717	1.692	1.670	1.680	1.727	1.711	1.801	1.796	2019	2064	2158	2245	470	